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AMERICAN JOURNAL OF ALTERNATIVE AGRICULTURE®

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TABLE OF CONTENTS

CAB INTERNATIONAL
Library Services
14 SEP 1995

Articles

50 ***Editorial*: Replicability in agricultural field experiments** • William Lockeretz

51 **Managing interference in a sweet corn-white clover living mulch system** • Albert Fischer and Larry Burrill

58 **Reduced chemical input cropping systems in the southeastern United States. I. Effect of rotations, green manure crops and nitrogen fertilizer on crop yields** • Larry D. King and Marc Buchanan

78 **Support in New England for certification and labelling of produce grown using integrated pest management** • Craig S. Hollingsworth, M.J. Paschall, Nancy L. Cohen, and William M. Coli

85 **Cereal and wool production in the Esperance Sandplain area of Western Australia: The need for a systems approach for sustainable agriculture** • Murray Fulton

91 ***Commentary*: The question of good science** • John E. Ikerd

Departments

Institute News—57 • Upcoming Events—77 • Resources—84 • Book Reviews—94 • Book Notices—96

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Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

The cover photo shows an overview of the cropping systems experiment located on a 6-hectare site at North Carolina State University Research Unit 9 near Raleigh. The ongoing experiment was established in September 1985 to study the agronomic and economic feasibility of cropping systems using reduced rates of chemical inputs.

Photo provided by Dr. Larry D. King, Department of Soil Science, North Carolina State University, Raleigh, NC.

EDITORIAL

Replicability in agricultural field experiments

William Lockeretz

In reading a report on an agricultural field experiment, a question that one legitimately can (and should) ask is: Under what other conditions would the conclusions still hold? Because agriculture is subject to so many sources of variability, we all know not to expect experimental results to be uniform across highly varied conditions. But we can still hope that they are not very sensitive to minor changes. For example, would the conclusions still hold on a field with the same soil type a few hundred meters away? Would they hold when the management system was changed slightly, let us say by as much as it typically varies among neighboring farmers who all use "standard" production practices? Unless we expect the answer to be "yes" — and certainly if we don't even know the answer — there isn't much point in doing field experiments. Isn't the whole idea behind scientific experimentation that it can teach us something that has broader applicability, something that can be abstracted from the specific circumstances under which the experiment was done?

Unfortunately, customary experimental protocols do not generally deal with this matter. Typically, they do not provide the necessary redundancy, such as more than one location, or more than one version of the same basic management system (apart from variations in the treatment variables that are the specific focus of study). Except for replication over years — which is customary in publishable field research — replication often means only that a given treatment is represented by multiple plots within the same experimental area. Such an experiment is thus a point measurement, its conclusions holding for sure only at that location, and leaving unaddressed a key question: Where else, if anywhere, do the conclusions hold?

An article in this issue suggests — indirectly and unintentionally — that neglecting this question can be very unfortunate. "Managing interference in a sweet corn-white clover living mulch system," by Albert Fischer and Larry Burrill, has precisely the redundancy that is needed to examine replicability empirically. The result is distressing.

The paper reports two related experiments, both involving a living mulch between rows of sweet corn. (I am referring to the two experiments reported in Tables 3 and 4. Another experiment reported in the same paper, in which planting density was varied systematically (Figs. 1 and 2), is not relevant here.) Although the two experiments are called "separate," there are two treatments that appear in both: row widths of 76 and 38 cm respectively (and correspondingly, stands of 66,000 and 79,000 plants/ha), with mulch. (These correspond to the second and third rows of Tables 3a and 4a in one experiment, and the first and second rows of Tables 3b and 4b in the other.) All other reported management variables (irrigation, fertilization, tillage, etc.) were identical between the two experiments, and the two experimental sites were nearby, on the same soil type.

The two experiments could hardly be more alike. Yet when we compare their results, they can hardly be called alike. The experimental protocols allow us to compare the two experiments with regard to four findings: how crop growth rate (CGR), yield of marketable ears, production of clover dry matter, and leaf area index (LAI) differed between wide and narrow rows in 1985. There is no problem with yield of marketable ears (which, fortunately, is among the most important outcome variables of the study). However, the other three present serious discrepancies.

If the authors, as they might have, had done only the first experiment, their conclusions would have been clear: going from wide to narrow rows raises both CGR and LAI substantially (CGR by 78%, from 7.6 to 13.5; LAI by 100%, from 1.3 to 2.6), and lowers clover dry matter (by 61%, from 1,811 to 711 kg/ha). All these effects were statistically significant (Tables 3a and 4a). But it happens that the other experiment provides us with independent measurements of the same effects, although that was not why the experiment was done. If it had been the only experiment — it, too, is self-contained, and might meaningfully have been done by itself — we would have reached a different conclusion: going from wide to narrow rows increases CGR by only 37% instead of 78% (from 15.2 to 20.9) and LAI by only 24% instead of 100% (from 1.07 to 1.33), and decreases clover dry matter by only 31% instead of 61% (from 1,580 to 1,090), with none of these effects statistically significant (Tables 3b and 4b).

continued on p. 93

The graciousness of Albert Fischer in cooperating with the preparation of this editorial is sincerely appreciated.

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Managing interference in a sweet corn-white clover living mulch system

Albert Fischer and Larry Burrill

Abstract. *Living mulches are vegetative covers that can be grown in association with row crops to reduce soil erosion, improve trafficability and suppress weeds. Interference by the living mulch can reduce yields of an associated crop. The interference between a white clover* (Trifolium repens *L. 'New Zealand') living mulch and sweet corn (*Zea mays *L. 'Golden Jubilee') was studied using an established clover sward that was mowed and then sprayed with 1 to 1.5 kg ai/ha of atrazine. Corn was planted at different densities and planting arrangements into a narrow band tilled in the clover. Interference by clover reduced corn yields by 12 to 39%. However, when corn row width was reduced from 0.76 to 0.38 m, competition among corn plants declined; they became more vigorous and clover-suppressive and reached even higher yields than conventional (no mulch) corn in 0.76 m rows. Similarly, sweet corn planted at a range of densities into a clover mulch killed by atrazine yielded more in equidistant planting than in wide (0.76 m) rows. A near equidistant corn planting arrangement can be a low-input alternative to achieve season-long clover suppression and thus minimize clover's competition with the intercropped corn.*

Key words: systematic designs, planting density, row width, intercropping, planting arrangement, competition, living mulch

Introduction

Weather in western Oregon makes agricultural fields prone to rain and wind erosion when the soil surface is without a protective vegetation cover. The breaking of soil aggregates by rain results in a surface crust that reduces water infiltration and promotes runoff and soil loss (Harvard et al., 1980). Soil, organic matter, fertilizers, and pesticides also may be moved from fields and deposited in streams and rivers (Burwell et al., 1975; Harvard et al., 1980; Daniel et al., 1980).

When sweet corn is harvested in Oregon, rain may be abundant, with the soil sparsely covered by vegetation. This makes the harvest difficult and leaves the fields vulnerable to erosion. The problem is worsened by weed control practices that leave much of the soil surface exposed.

Living covers (white clover, vetch, and others) growing in association with corn reduce erosion and suppress weeds (Hargrove, 1982; Sweet, 1982). According to Vrabel (1983), intercropping sweet corn with a legume cover crop also increases the availability of nitrogen to sweet corn. Unsuppressed white clover intercropped with sweet corn usually will lower corn yields (Hartwig, 1977; Lang et al., 1956; Sweet, 1982). This interference — the negative effect of one plant on another through competition, allelopathy, or both — must be minimized without a significant increase in production costs if living mulches are to be feasible for farmers. Management practices should optimize the capacity of sweet corn to suppress the growth of the mulch. Before management practices for these intercropped species can be defined, the factors involved in interference between sweet corn and white clover must be known.

The research reported had two goals: to understand the interactions among sweet corn plants and between sweet corn and white clover when sweet corn is grown with a white clover living mulch; and to find a cropping technique that minimizes the reduction in corn yield from clover interference.

We conducted two types of experiments. First, conventional field experiments were used to quantify the effect of clover on sweet corn yield, to study sweet corn and clover responses to changes in sweet corn densities and planting patterns, and to assess the ability of sweet corn to suppress clover growth. Second, we evaluated the productivity of sweet corn growing in a suppressed clover sward for a range of densities within two different planting arrangements, using systematic designs in which planting density increased continuously (Bleasdale, 1967; Nelder, 1962; Freyman and Dolman, 1971).

Materials and Methods

Sweet corn density and distribution in the presence of a living mulch

We assessed the effect of corn densities and planting pattern on the yield of sweet corn (*Zea mays* L. var. 'Golden Jubilee') growing in association with white clover (*Trifolium repens* L. var. 'New Zealand') near Corvallis, Oregon, on a fine-silty, mixed mesic Cumulic Ultic Haploxeroll soil. The experimental treatments were combinations of high and low sweet corn

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densities with two row spacings. Thus four planting patterns of sweet corn were evaluated (Table 1).

Plots were 6 by 10 m, and treatments were arranged in a randomized complete block design with four replications. A 2-year-old white clover sward was mowed prior to planting corn in 10 to 15-cm-wide strips tilled through the clover at the specified row spacing. Two John Deere Flexiplanter 70 units mounted behind the tiller placed corn seeds 2-cm deep into the tilled band. The experiment was conducted under sprinkler irrigation in 1984 and 1985. The sequence of tillage, planting, clover suppression, and fertilization is shown in Table 2.

To assess clover interference on corn growth, we sampled corn plants sequentially for growth analysis in both growing seasons. The sampling schedule in 1984 was 20, 35, 50, 64, and 121 days after planting (DAP) corn; in 1985, it was 25, 46, 64, and 98 DAP. Total above-ground biomass of two representative corn plants per plot was harvested at each sampling date, and leaf area and dry matter were determined for each plant (plants were dried for 5 days at 70°C and weighed). From these data, we calculated mean crop growth rates (CGR) following Hunt (1982).

Clover foliage was sampled in 1985 by clipping an area 18 by 50 cm between sweet corn rows. The clover samples were dried for 3 days at 70°C and weighed. At 52 DAP, high contrast photographs of the corn canopy were taken with a 7.5 mm fish-eye lens mounted on a 35 mm camera, using Kodalith orthofilm 6556 type 3. The camera was placed on the ground at the center of each plot, pointing skyward. With the resulting high-contrast slides we estimated canopy coverage according to the method of Chan et al. (1986).

In both years, when corn moisture was 72%, ears with husks were harvested from three 1 m sections of row per plot, from an area where no previous foliage sampling was taken. Only ears with husks longer than 15 cm (marketable ears) were harvested, and their fresh weight recorded.

Conventional vs. mulch systems

We studied the interference of a clover mulch with sweet corn productivity in 1984 and 1985. The treatments were: 1) conventional surface tillage (no mulch) with a rotary tiller (1984) or a moldboard plow (1985), with sweet corn planted at 66,000 plants/ha in rows 76 cm apart; 2) the same row width and density of sweet corn as in 1), but planted into a 2-year-old herbicide-suppressed white clover sward; 3) sweet corn (79,000 plants/ha) seeded into herbicide-suppressed clover in 38 cm rows. This treatment was added in 1985 to assess the effect of narrow rows on sweet corn yield and clover growth. (In this treatment the planting procedure resulted in a corn density 1.26 times higher than in the other treatments.) In treatments 2) and 3), corn was seeded in a band tilled in the clover sod as described in the preceding section. Soil type, timing and procedures for tillage, planting, clover suppression, biomass sampling, irrigation, fertilization, and harvest were the same as in the preceding experiment (Table 2).

Table 1. Treatments in the sweet corn density and planting pattern experiment in the presence of a white clover living mulch.

	Treatments			
Density (plants/ha)	66,000	79,000[1]	131,000	131,000
Row width (cm)	76	38	76	38
Plant spacing (cm)	20	33	10	20

[1] The corn planter we used did not allow seeding at 66,000 plants/ha in rows 38 cm apart. The closest density was 79,000 plants/ha.

Table 2. Sequence of tillage, planting, fertilization, and clover suppression in experiments on sweet corn densities and planting patterns in the presence of a living mulch, and on conventional vs. mulch systems.

Days after planting	1984
-8	Surface tillage in the treatment without clover.
0	Strip tillage in clover, and corn planting (June 25). Fertilization: N, P, and K at 4, 6, and 4 kg/ha, banded 2.5 cm to the side and below corn seeds. Clover suppression: atrazine and alachlor at 1.7 and 2.2 kg a.i./ha, respectively, sprayed at a volume of 200 l/ha on a 15-cm-band over the seeded rows.
36	Fertilization: 100 kg N/ha (urea) applied at base of corn plants.
42	Clover suppression: atrazine at 1.1 kg a.i./ha.
	1985
-11	Surface tillage in the treatment without clover
-4	Strip tillage and fertilization: N (urea) and P (superphosphate) at 30 and 63 kg/ha, respectively, applied 10 cm deep in the tilled band.
0	Sweet corn planting (June 3).
1	Clover suppression: atrazine and crop oil at 1.5 kg a.i./ha + 2 l/ha, respectively, sprayed over 15 cm tall clover.
10	Clover suppression: clover mowed between corn rows.
45	Fertilization: 90 kg N/ha (urea), basal application.

Density experiments

To determine the best corn density and seeding pattern to grow under the influence of a constant background level of white clover, sweet corn was planted into a suppressed clover sward in 1985 at systematically increasing densities, and in two different planting patterns. We used two experimental designs:

1) A fan design (Bleasdale, 1967; Nelder, 1962), in which the plants were arranged almost in squares. Twelve values of corn density ranged from 25,000 to 173,000 plants/ha in successive rows (arches), of which only 8 are shown in Figure 1a. Plots were 4 by 5 m, placed at different orientations on a 3-year-old white clover sward. Clover was mowed and a 10 cm planting band was tilled over each arch with a rotary tiller. Corn was hand planted (June 23) into the tilled band. Fertilizer was broadcast over the plots at 7 DAP (30 kg N and 68 kg P/ha as urea and calcium superphosphate), and at 15 DAP (90 kg N/ha as urea). Atrazine and crop oil (1.5 kg a.i./ha and 2 l/ha, respectively) were applied at 8 DAP to suppress clover growth. We harvested five corn plants at each density when kernel moisture was 70%, and recorded the weight of husked ears more than 15 cm long. One arch at each extreme of the plots was discarded as a border row.

2) In a second experiment, the systematic design of Freyman and Dolman (1971) was used, where the row width was held at 76 cm for all densities (Figure 1b). Thus a sequence of 11 densities (25,000 to 172,000 plants/ha) was planted in 11 parallel rows in each of four 8 by 7 m plot. The plots were established at different orientations on a 3-year-old white clover sward. Planting, fertilizing, clover suppression, and harvesting were conducted as in experiment 1). Data from both systematic experiments were statistically analyzed by regression.

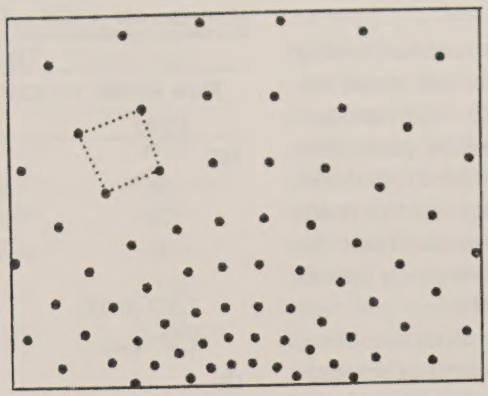

Figure 1a. Systematic density design with an approximately square planting arrangement (only eight arches represented here).

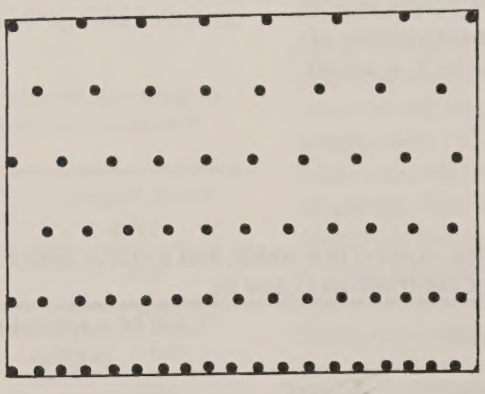

Figure 1b. Systematic density design for spacing experiments with set row widths (only six rows represented here).

Results and Discussion

Clover interference and sweet corn planting patterns

When corn was planted in 0.76 m rows, its growth and productivity were depressed when clover was present (Tables 3a and 4a). Competition for water and nutrients is usually involved in such interference (Altieri and Liebman, 1986). Although yield was not significantly reduced in 1985, clover should be suppressed for this system to work successfully (Sweet, 1982).

Sweet corn in narrow rows with a clover mulch showed higher growth rates (Table 3), more marketable ears per plant (Table 5), and even higher crop yields than in conventional plots without clover (Table 4). Enhanced productivity with narrow rows had also been observed with corn growing alone (Mack, 1972), or with alfalfa (Peterson, 1985). Also, as noted by Harper et al. (1980), corn in narrow rows suppressed clover growth better (Table 4), since higher growth rates in this planting arrangement resulted in leafier corn plants (Table 4) that shielded the ground more completely (Table 6). Increasing ground cover suppressed clover growth (R^2=0.33, p=0.02). Plants in wide rows grew close to each other within the row (Table 1), whereas the greater separation between plants in the narrow rows reduced competition among them. This made them more productive and clover-suppressive, as was also noted

by Altieri and Liebman (1986) and by Fischer and Miles (1973).

Doubling corn density in either planting arrangement did not increase yields nor suppress clover (Table 4b). High corn density resulted in more crowded plants with fewer marketable ears (Table 5). In the 76 cm rows, in spite of the high density, much uncovered ground remained (Table 6), which allowed considerable clover growth and competition (Table 4b).

Stepwise regression analysis, using models with high coefficients of determination and low mean square errors, identified the aspects of corn growth and clover suppression most closely affecting marketable corn ear production. In 1984, corn leaf area per plant and plant biomass accounted for 70% of the variance in corn yield; in 1985, corn biomass, clover biomass, and canopy ground cover were the variables most closely associated with corn yields (R^2=0.87). Changes in corn densities and planting arrangements affected these variables (Tables 3, 4, and 6).

Table 3. Effect of planting density, row width, and clover mulch on mean crop growth rate (CGR) of corn. Data are from two sets of experiments (a and b).

Treatment			CGR (g m^{-2} day^{-1})	
Row width (cm)	Corn density (ha^{-1})	Clover mulch	1984	1985
(a)				
76	66,000	no	16.2a[1]	26.9a
76	66,000	yes	6.7b	7.6c
38	79,000	yes	—	13.5b
LSD (0.05)			7.8	5.3
CV (%)			30	19
(b)				
76	66,000	yes	3.4d	15.2b
38	79,000	yes	9.5b	20.9ab
76	131,000	yes	7.1c	27.4a
38	131,000	yes	13.4a	24.1a
LSD (0.05)			1.9	8.5
CV (%)			15	24

[1] Values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).

Table 4. Effect of planting density, row width, and a clover mulch on sweet corn yield, leaf area index, and clover growth. Data are from two sets of experiments (a and b).

Treatment			Yield of marketable ears (kg/ha)		Clover dry matter, 64 DAP[1], 1985 (kg/ha)	Leaf area index, 47 DAP	
Row width (cm)	Corn density (ha^{-1})	Clover mulch	1984	1985		1984	1985
(a)							
76	66,000	no	29,280a[2]	33,594b	—	5.9a	2.9a
76	66,000	yes	17,760b	29,519b	1,811a	1.2b	1.3b
38	79,000	yes	—	42,522a	711b	—	2.6a
LSD (0.05)			8,552	8,799	323	2.3	1.1
CV (%)			16	14	11	29	29
(b)							
76	66,000	yes	13,678c	22,820b	1,580ab	0.61c	1.07b
38	79,000	yes	32,710a	37,660a	1,090b	1.58b	1.33b
76	131,000	yes	10,469c	25,298b	2,030a	1.03c	1.62b
38	131,000	yes	28,452b	35,980a	1,090b	2.98a	3.80a
LSD (0.05)			3,407	5,062	623	0.55	0.84
CV (%)			10	10	27	8	14

[1] Days after planting.
[2] Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).

Table 5. Effect of planting density and row width on the number of marketable ears of sweet corn growing with a clover living mulch.

Treatment			Ears > 15 cm long (no. per plant)	
Row width (cm)	Corn density (ha^{-1})	Clover mulch	1984	1985
76	66,000	yes	0.6b[1]	1.03b
38	79,000	yes	0.9a	1.44a
76	131,000	yes	0.3c	0.58c
38	131,000	yes	0.6b	0.79bc
LSD (0.05)			0.28	0.26
CV (%)			29	17

[1] Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).

Table 6. Between-row ground cover (56 DAP) by sweet corn canopies growing in four planting arrangements with clover or as conventional sweet corn monoculture.

Row width (cm)	Corn density (ha^{-1})	Clover mulch	Ground cover (%)
76	66,000	no	67a[1]
76	66,000	yes	28c
38	79,000	yes	53ab
76	131,000	yes	42b
38	131,000	yes	68a
LSD (0.05)			15
CV (%)			19

[1] Within columns, values followed by the same letter are not statistically different according to Fisher's protected LSD (p=0.05).

Systematic density experiments

The addition of crop oil (used only in this experiment) made the suppression of the recently mowed clover sward by atrazine too harsh. The sward was killed, unlike in the two other experiments conducted that year, where clover was much taller when sprayed and no oil was used. Therefore, corn in the systematic experiment was planted into a dead clover cover.

In both planting arrangements, corn planted in a nearly equidistant pattern yielded more than in 76 cm rows (Figure 2) where plants were more crowded within the rows. Therefore, greater competition among corn plants must have occurred in the wide row arrangement, which would explain the lower yields obtained with this planting method; lower yields were also found by Brown et al. (1970). The higher productivity of the narrow row arrangement, observed in the preceding section, was confirmed by this experiment for a wide range of planting densities. The absence of a competing clover mulch may explain why yields were not curbed at high densities as in the preceding experiments, where twofold density increases did not improve yields (Table 4b).

Summary and Conclusions

The primary objective of this investigation was to study the competitive interactions in a system involving sweet corn and a white clover living mulch. We sought a cropping technique that minimized clover interference with corn. Sweet corn was grown on conventionally-tilled soil, and also intercropped with a living mulch of clover at different densities and planting arrangements. Yield losses occurred when sweet corn was intercropped with the clover mulch. Clover needs to be suppressed strongly to prevent excessive competition with the associated crop. However, since clover is intended as a perennial living cover, suppression should not kill it. Season-long clover suppression would thus require several chemical or mechanical interventions. Therefore, complementary vegetation management techniques are needed for prolonged living mulch suppression, while keeping external inputs low. A near-equidistant corn planting approach using narrow rows can be a feasible option to mitigate corn yield losses in a corn-clover living mulch system.

Serious erosion and trafficability problems seem the strongest reasons for living mulch use by sweet corn growers in Oregon. Other benefits from the mulch, such as reduced annual weed populations, increased soil nitrogen availability, and use of clover as a forage to be sold or consumed on the farm, may also be relevant to farmers. Managing this cropping approach may be complex, and would require technical support and changes in farming practices such as adapting the harvesting equipment to work in narrow rows.

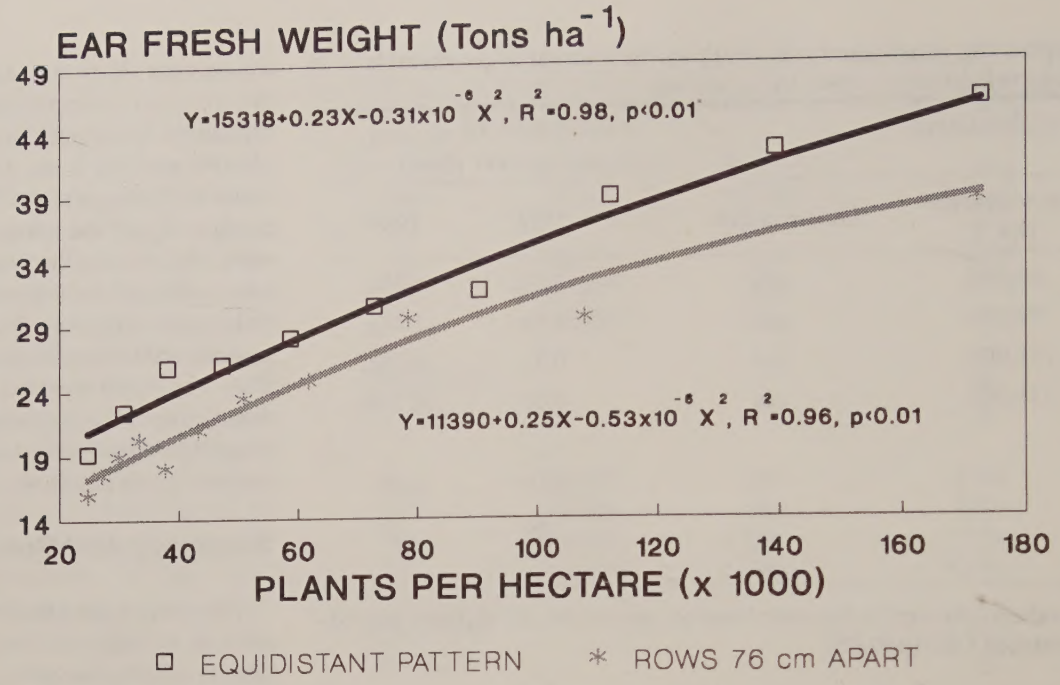

Figure 2. Yield of marketable sweet corn ears in 1985, when it was planted at different densities, in a nearly equidistant pattern or in rows 76 cm apart. The regression lines are statistically different ($p < .01$) according to an F test comparing all the coefficients in the models.

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Reichelderfer Named Director of Institute's Policy Studies Program

Dr. Katherine H. Reichelderfer has been named the Director of the new Policy Studies Program at the Henry A. Wallace Institute for Alternative Agriculture. The program will respond to the compelling need for sound facts and information on the sustainability of agriculture to help inform the national policymaking process, including development of the 1995 farm bill.

Since 1991, Dr. Reichelderfer has been the Associate Administrator and, now, the Acting Administrator, of the Economic Research Service (ERS) at the USDA. She joined the ERS as a research economist in 1977, and has since led and conducted ERS research and educational programs in pest management, farm inputs, agricultural productivity, international economics, and natural resources and technology.

During 1990-1991, Dr. Reichelderfer was a Senior Fellow and Director of the Agriculture, Environment and Food Safety research program at the Washington-based National Center for Food and Agricultural Policy, located in Resources for the Future.

She earned a Ph.D. in agricultural and resource economics from the University of Maryland in 1977.

Dr. Reichelderfer will assume her new duties on September 1.

Agriculture Committees Urged to Protect Family Farms

Fifteen local and national organizations, including the Wallace Institute, have written to the members of the House and Senate Agriculture Committees, urging them to support budget proposals that "protect family farm income and encourage voluntary efforts to protect the environment"—and at the same time, achieve necessary spending reductions, assure a safe and abundant food supply, and provide increased funding for food assistance programs.

As part of the budget reconciliation package, the groups asked for support for establishing a "graduated triple base;" making the marketing loan for wheat and feed grains discretionary; requiring material participation of farm program participants; repealing the three-entity rule and attributing payments received by legal entities to natural persons; making adjustments in the integrated farm management program; directing the USDA to implement the Targeted Option Payment Program; and establishing an "environmental diversion bonus."

ATTRA Funding Increase Urged by Several Groups

Several farm organizations, including the Wallace Institute, have written to House Interior Subcommittee Chair Sidney Yates to urge increased funding for the Appropriate Technology Transfer for Rural Areas (ATTRA) program in Fayetteville, AR. The National Center for Appropriate Technology, which manages ATTRA, has requested funding of $1.5 million for FY94; the Department of Interior has requested $1.289 million, which is the same funding level it received last year. In supporting the $1.5 million request, the groups described ATTRA as "a key organization in transferring sustainable agriculture technology."

Farm Profiles Invited

For its new department on alternative agriculture profiles, the *AJAA* welcomes short articles describing farmers who have adopted interesting alternative practices. The articles should include five elements: a brief description of the farm; the problems that made the farmer look for an alternative approach and the reasons why the alternative seemed plausible; a summary of the basic principles behind the alternative (possibly in a sidebar if it interrupts the flow of text); a discussion of how well the alternative has worked; and a discussion of the applicability of the alternative for other farms. The length should be 1500 to 2000 words.

Submissions must be accompanied by a release, signed by the farmer, giving permission for this material to be published in the *American Journal of Alternative Agriculture*. Vol. 3, No. 4, of the *AJAA* has a further description of the department (page 188); or query the editor for further information. Send submissions to the Editor, *AJAA*, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770-1551.

Letters To The Editor Invited

The *AJAA* welcomes letters, short or long, commenting on articles in this journal or sharing ideas likely to be of interest to other *AJAA* readers. Since our space is limited, we do reserve the right not to publish all letters or, at times, to publish only excerpts from them. To take part in this exchange of ideas, write to: Editor, *AJAA*, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770-1551.

Reduced chemical input cropping systems in the southeastern United States. I. Effect of rotations, green manure crops and nitrogen fertilizer on crop yields

Larry D. King and Marc Buchanan

Abstract. *Interest in reducing purchased chemical inputs to reduce production costs and avoid possible environmental damage prompted this 7-year study. Two management systems, current management practices (CMP) and reduced chemical inputs (RCI), were evaluated for four crop sequences from 1985 through 1992: continuous grain sorghum; continuous corn; a 2-year rotation of corn and double-cropped winter wheat and soybean; and a 4-year rotation of corn, winter wheat/soybean, corn, and red clover hay (changed in 1989 to a 3-year rotation of corn, red clover hay, and wheat/soybean). No-till planting and recommended rates of fertilizer and pesticides were used in the CMP system. In the RCI system, N was supplied by a crimson clover green manure crop or the red clover in the rotation. Weed control was by chisel plowing, disking, and cultivation.*

Crimson clover top growth accumulated from 70 to 180 kg N/ha, red clover from 77 to 130 kg N/ha. Rotating crops increased corn yield with CMP but not with RCI. In dry years, corn yields were low (less than 3000 kg/ha), corn did not respond to fertilizer N, and yields generally were higher with CMP than with RCI. With adequate rain, yield of all RCI treatments were the same as yield in CMP continuous corn receiving no fertilizer N. Johnsongrass competition was the main reason for low yields in the RCI treatments. Soybean yields were higher with CMP in 4 years and higher with RCI one year. Wheat and grain sorghum yields were higher with CMP than with RCI. A dramatic decline in johnsongrass in sorghum was noted in 1989, and several plots remained relatively free of johnsongrass through 1992.

Management decisions made during the experiment included the degree of input reduction in RCI; whether to either end or modify unproductive treatments; whether to use newly available varieties and pesticides; whether to suspend the experiment to eliminate johnsongrass; and how to add new treatments while retaining the original treatments.

Key words: crop rotation, current management practice

Introduction

When war-related technology and manufacturing facilities were converted to peacetime uses after World War II, fertilizers became abundant and new pesticides became available to control insects and weeds. As a result, farmers tended to eliminate rotations, or at least reduce their length and stop using green manure crops to supply N. Yields increased and labor requirements decreased with the new technology, but in the 1960s, some people began to question its effects on the environment. The sustainability of farm inputs was further challenged when the price of N and P fertilizers doubled after the oil embargo of 1973. In the 1980s, input costs continued to increase much faster than the prices farmers received for their crops.

These concerns led people to wonder whether the use of purchased inputs, particularly fertilizers and pesticides, could be reduced without a large decrease in yields. Studies by the U.S. Dept. of Agriculture (1980), Lockeretz et al. (1981), and the National Research Council (1989) showed that some farmers ran successful enterprises using no manufactured pesticides and fertilizers, or using them at low rates. The USDA report recommended that research be initiated to gain more information on the feasibility of farming with reduced chemical inputs.

Before these studies, an experiment had been started in Nebraska to compare four treatments. Continuous corn (*Zea mays*) received recommended rates of fertilizer and herbicides; a rotation of corn-soybean (*Glycine max*)-corn-oat (*Avena sativa*)/sweet clover (*Melilotus officinalis*) received three different chemical treatments: recommended rates of fertilizer and herbicides; fertilizer with no herbicide; and feedlot manure with no herbicides (Sahs and Lesoing, 1985; Andrews et al., 1990). Corn grain yield in the manure/no herbicide treatment was equal to or greater than that in the continuous corn treatment in 11 out of 12 years. Compared with the other rotation treatments, yields with manure and no herbicide were comparable to those with fertilizer and herbicides in 8 years and comparable to those with fertilizer and no herbicides in 10 years. Soybean yield in the manure/no herbicides treatment was comparable to the other treatments' yields in 8 of the 12 years. Oat yield with manure and

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no herbicides was equal to or greater than yields in the other treatments each year. In 1981, another reduced input experiment was started at the Rodale Research Center in Pennsylvania (Andrews et al., 1990; Liebhardt et al., 1989).

Three 5-year rotations were compared:

- *Low-input with livestock*: corn-soybean-corn silage-wheat (*Triticum aestivum*)/red clover (*Trifolium pratense*)-red clover; manure applied to the corn crops
- *Low-input/cash grain*: corn-soybean-oats/red clover-corn-oats/red clover
- *Conventional*: corn-corn-soybean-corn-soybean; recommended rates of fertilizer and pesticides

The experimental site had been in a conventionally managed corn-wheat rotation for several years. Soil P and K concentrations were high enough that P and K were applied only in starter fertilizer in the conventional treatment (15 kg P and 9 to 28 kg K/ha). Soybean and small grain yields were not adversely affected by conversion to a low-input system. Generally, corn grain yield in the conventional treatment was higher than in the low-input systems the first 4 years, but for the next 3 years yields generally were similar in all treatments.

The Nebraska and Pennsylvania studies showed that yields in reduced chemical input cropping systems either did not suffer greatly or recovered after a few years. Like these successful experiments, most successful organic and reduced input farms are located outside the southern U.S. (U.S. Dept. of Agriculture, 1980; Lockeretz et al., 1981; National Research Council, 1989). Therefore, our objective was to learn whether it is agronomically feasible to substitute legumes and mechanical weed control for fertilizer N and pesticides in cropping systems commonly used in the southeastern U.S.

Methods

Crop sequence and management systems

Four *crop sequences* were established:

- Continuous corn
- 2-year rotation: corn-wheat/soybean
- 4(3)-year rotation: corn-wheat/soybean-corn-red clover hay. After the first cycle, this was changed to a 3-year rotation: wheat/soybean-corn-red clover hay
- Continuous grain sorghum (*Sorghum bicolor*).

Two *management systems* were used:

- Current Management Practices (CMP) = no-till planting and recommended rates of herbicides, insecticides, and fertilizer
- Reduced Chemical Inputs (RCI) = conventional tillage; N supplied either by a winter green manure crop of crimson clover (*Trifolium incarnatum*) or by the residual N from red clover managed for hay; cultivation for weed management; and no insecticides.

We hypothesized that yields would be lower with RCI management than with CMP management. Therefore, to allow a better comparison between CMP and RCI, an N fertilizer variable was included for corn and wheat in the CMP treatments. (Mehlich 3-extractable soil P and K concentrations were high enough that no P and K fertilizers were required.) The specific treatments are listed in Table 1.

We anticipated that as the experiment progressed and knowledge was gained, we would need to add treatments or modify existing treatments. Therefore, we added some 'standby' treatments (maintained in a corn-soybean rotation) that could be converted later to treatments suggested by the results of the experiment. Also, after the experiment was set up, we found that the P and K fertility variables we had planned to use with RCI treatments were not feasible, so that we had 16 replications of some treatments. Thus we could modify the treatments but retain at least four replications of the initial treatments. Over the 7-year period, we modified several treatments and added three rotations. We will report the results in later articles.

The experiment was established in September 1985 on a 6-ha site at North Carolina State University Research Unit 9. The soil series is Cecil (Typic Kanhapludults, clayey, kaolinitic, thermic) with 2 to 6% slope and moderate erosion. Treatments were arranged in a randomized complete block design with four replications. Because slope and the texture of the surface soil varied across the field, blocks were laid out based on visual estimates of surface texture and landscape position. For example, the first block was located mainly on a level ridge top. The second was on the side slope on two sides of the first block. The third block was generally on a ridge top; the surface texture was predominately clay loam. The fourth block was on a ridge top and side slope, but the texture was predominately sandy loam. Plots were 8 × 30 m. The area previously had been used for corn silage for several years. After silage harvest in 1985, glyphosate was applied at 5 l/ha to prevent regrowth of johnsongrass (*Sorghum halepense*).

Current management practices

Nitrogen fertilizer (NH_4NO_3) was applied to corn and wheat at 0, 50, 75, and 100% of the recommended rate (Table 1). Application rates for corn were reduced by 25% when soybean or red clover hay preceded corn. Corn does not respond to split applications of N fertilizer on these soils (Kamprath et al., 1973); therefore, all the N fertilizer was broadcast within two weeks after planting. Half the N fertilizer for wheat was applied at planting, the rest in February. The recommended N rate for grain sorghum was broadcast at planting. Both entry points were included in the 2-year rotation, but we could use only one N rate (the recommended rate) in treatment C2xd. Similarly, we could establish only one entry point in the 4(3)-year rotation.

Pesticides used are shown in Table 2. Although corn, soybean and wheat were no-till planted, corn was cultivated twice in 1988 because of heavy johnsongrass infestation. One exception to no-till planting was in 1991: wheat planted no-till was established so poorly that we tilled the plots with a field cultivator and disk and replanted the wheat. A field cultivator and disk were used to prepare the seedbed for sorghum because of the heavy johnsongrass infestation before planting. A chisel plow, disk and cultipacker were used to prepare the seedbed for red clover.

Table 1. Treatments.[1]

Code[2]	1985-86		1986-87		1987-88		1988-89		1989-90		1990-91		1991-92		Fert N (kg/ha)	
	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	Corn or sorg	Whe
Current Management Practices (CMP)[3]																
Continuous corn																
C1a		corn		corn		corn		corn		corn		corn		corn	0	-
C1b		"		"		"		"		"		"		"	70	-
C1c		"		"		"		"		"		"		"	105	-
C1d		"		"		"		"		"		"		"	140	-
2-yr rotation																
C2a	(wheat)	bean		corn	(wheat)	bean		corn	(wheat)	bean	——— discontinued ———				0	
C2b	"	"		"	"	"		"	"	"		corn	(wheat)	bean	52	4
C2c	"	"		"	"	"		"	"	"		"	"	"	79	6
C2d	"	"		"	"	"		"	"	"		"	"	"	105	9
C2xd		corn	(wheat)	bean		corn	(wheat)	bean		corn	(wheat)	bean		corn	105	9
4-yr rotation									**3-yr rotation**							
C4a	(wheat)	bean		corn	(RedCl)	RedCl	(RedCl)	corn	(wheat)	bean		corn	(RedCl)	RedCl	0	
C4b	"	"		"	"	"	"	"	"	"		"	"	"	52	4
C4c	"	"		"	"	"	"	"	"	"		"	"	"	79	6
C4d	"	"		"	"	"	"	"	"	"		"	"	"	105	9
Continuous grain sorghum																
CS		sorg		sorg		sorg		sorg		sorg		sorg		sorg	90	
Reduced Chemical Inputs (RCI)[4]																
Continuous corn																
R1	(CriCl)	corn	(CriCl)	corn	(CriCl)	corn	(CriCl)	corn	(CriCl)	corn	(CriCl)	corn	(CriCl)	corn	0	
2-yr rotation																
R2	(wheat)	bean	(CriCl)	corn	(wheat)	bean	(CriCl)	corn	(wheat)	bean	(CriCl)	corn	(wheat)	bean	0	
R2x	(CriCl)	corn	(wheat)	bean	(CriCl)	corn	(wheat)	bean	(CriCl)	corn	(wheat)	bean	(CriCl)	corn	0	
4-yr rotation									**3-yr rotation**							
R4	(wheat)	bean	(CriCl)	corn	(RedCl)	RedCl	(RedCl)	corn	(wheat)	bean	(CriCl)	corn	(RedCl)	RedCl	0	
R4x	(RedCl)	RedCl	(RedCl)	corn	(wheat)	bean	(CriCl)	corn	(RedCl)	RedCl	(wheat)	bean	(CriCl)	corn	0	
R4y	(RedCl)	corn	(wheat)	bean	(CriCl)	corn	(RedCl)	RedCl	——— discontinued ———						0	
R4z	(CriCl)	corn	(RedCl)	RedCl	(RedCl)	corn	(wheat)	bean	(CriCl)	corn	(RedCl)	RedCl	(wheat)	bean	0	
Continuous grain sorgum																
RS	(CriCl)	sorg	(CriCl)	sorg	(CriCl)	sorg	(CriCl)	sorg	(CriCl)	sorg	(CriCl)	sorg	(CriCl)	sorg	0	

[1] Winter crop in parentheses. CriCl = crimson clover; sorg = grain sorgum; bean = soybean; RedCl = red clover.
[2] a,b,c and d indicate N fertilizer rate; x,y and z indicate different entry points into the rotation.
[3] Herbicides used in all treatments (see Table 2); soil insecticide used for corn 1986-1990; corn,wheat, bean planted no-till.
[4] Herbicide used only on wheat in fall of 1991 and banded on corn and bean 1992; no insecticides in any treatments. Primary tillage (chisel plow, disk) and cultivation.

Table 2. Herbicides used in the current management practices (CMP) system (liter/ha, except where indicated).[1]

Corn		
At planting		
1986-92	alachlor (Lasso)	7.4
1986-92	glyphosate (Roundup)	5
1986-92	atrazine (AAtrex)	5
Post-emergence		
1987	linuron (Lorox 50WP) (directed spray)	3
1987-88	glyphosate (tractor- mounted rope wick)	
1989-92	nicosulfuron (Accent) (broadcast sprayed)	0.035 kg/ha
Sorghum[2]		
At planting		
1986-89, 92	alachlor	5
1986-89, 92	atrazine	3.7
1986-87	glyphosate	2
Post-emergence		
1987-88	glyphosate (tractor-mounted rope wick)	
1990-91	2,4-D (spot sprayed)	
Soybean		
At planting		
1986-92	alachlor	7.4
1986-92	glyphosate	6
1989-92	imazaquin (Scepter)	0.8
1986-88	linuron	3 kg/ha
Post-emergence		
1986-92	sethoxydim (Poast) (broadcast sprayed)	1.8
Wheat		
At planting		
1987	glyphosate	5
1991	diclofop (Hoelon)	3.3

[1] From 1986 to 1990, the insecticide carbofuran (Furadan) was dropped with the corn seed at a rate of 9 kg/ha. No other insecticides were used.

[2] From 1986 to 1988, seed treated with a safener was used so that alachlor could be used. In 1989, we noted apparent herbicide damage and discovered that the seed obtained in 1989 had not been treated. Treated seed were not available again until 1992.

Reduced chemical input

Nitrogen was supplied to grain sorghum by a crimson clover green manure crop and to corn by crimson clover or by spring regrowth of red clover managed for hay the previous year (Tables 1 and 3). Because of insufficient N carryover for wheat after corn, we changed the 4-year rotation to a 3-year rotation in which red clover hay preceded wheat. The fall regrowth of clover was plowed before planting wheat.

To retain appreciable plant residue on the surface, we did not completely incorporate the clover, for example with a moldboard plow. From 1986 through 1988, we used a disk and sometimes a field cultivator to kill the green manure crop. These implements did not kill the clover effectively, so in spring 1989 we modified a Hiniker cultivator to consist of three chisel plow shanks and points, each preceded by a coulter. Since the shanks were spaced at 1 m, repeated passes were made moving about 33 cm laterally each time to achieve three furrows per meter. With this technique, we could chisel plow the plots without the problem of clogging that would occur with a conventional chisel plow. This technique probably would perform similarly to a commercially available tillage implement commonly called a coulter chisel (a row of coulters followed by chisel plow shanks). The plots were then disked at least twice. These techniques killed the crimson clover adequately and left approximately half the clover residue on the surface. However, some red clover survived this tillage and competed with the following corn crop. Corn was planted with the same no-till planter used for the CMP treatments.

In years when ridges were present because of corn cultivation in RCI systems, we disked the plots lightly to remove the ridges before planting wheat with a no-till drill. After wheat harvest the following summer, we disked stubble twice before planting soybean. Corn, sorghum, and soybean were cultivated with a rolling cultivator in 1986 and 1987, but it plugged badly with clover residue. Beginning in 1988 the Hiniker cultivator (designed for high surface residue conditions) was used. No cultural practices were used to control weeds in wheat or red clover.

Table 3. Green manure management.

Code	Crop sequence	Management
R1	Continuous corn	Crimson clover drilled at 25 kg/ha after corn harvest (Oct. 2-10)
R2, R4	2- and 4(3)-year rotation	1986-1991: crimson clover aerially seeded at 25 kg/ha into soybean after lower leaves began falling (Oct. 24-28) 1991: crimson clover planted at 6 kg/ha with wheat to provide a thin stand to mature seed for natural reseeding in soybean in 1992.
R4	4(3)-year rotation	Red clover drilled at 15 kg/ha in prepared seedbed after corn harvest (Oct. 2-10); cut for hay the following spring and summer for corn: spring regrowth used as a green manure for wheat (subsequent 3-year rotation): regrowth after last hay harvest used as green manure crop[1]
RS	Sorghum	Crimson clover allowed to mature seed and naturally reseed each year (crimson clover drilled in Oct. 1985 only)

[1]Time from last hay harvest to plowing: 1990, 19 Sept. to 23 Oct.; 1991, 21 Aug. to 21 Oct.; 1992, 6 Aug. to 27 Oct.

We delayed corn planting approximately 2 weeks in the RCI treatments compared to the CMP treatments to allow additional biomass and N to accumulate in the clover green manures (Table 4). In the Piedmont of North Carolina, corn yield normally declines as planting is delayed past April 15 (Anderson and Wagger, undated). Therefore, the planting date was a compromise between increasing yield because of increased N in the clover, versus lowering yield because of later planting.

Our original intent was to use no herbicides in the RCI management systems. However, wheat became so infested with ryegrass (*Lolium multiflorum*) that diclofop (Hoelon) was applied to RCI wheat in Fall 1991. Because johnsongrass could not be controlled with cultivation and rotation, we band-applied nicosulfuron (Accent) on corn and Poast on soybean at second cultivation in 1992.

Planting, sampling and harvesting

Information on planting and cultivation is shown in Table 4. A different corn cultivar was used for each planting date, but after 1989 we decided that DeKalb 689 would be suitable for both dates. Corn populations at harvest were low the first few years, particularly in the RCI treatments (less than 45,000 plants/ha) so seeding rate was increased several times (Table 4). Because the needed seeds were unavailable, we had to use several sorghum and wheat cultivars during the experimental period (Table 4).

Rows for corn, soybean and sorghum were 1 m wide. However, in 1990 and 1991, we used 50-cm spacing in sorghum to achieve faster canopy closure over the row middles to improve weed control. The 50-cm spacing was no more effective than 1 m, so 1 m was used in 1992. Spacing for wheat was 18 cm.

Before plowing crimson and red clover green manures, we measured the clover plus weed biomass by cutting plants at the soil surface within a 0.25 m-square frame at four locations in each plot. A subsample was taken for chemical analysis. Because of the increasing infestation of ryegrass in 1990 and 1991, samples collected in 1992 were separated into clover and ryegrass. We measured yield of red clover hay by harvesting a 1-m wide strip the length of the plot. The center two rows of corn, soybean, and sorghum plots were harvested with a conventional combine. The same combine was used to harvest a 2-m wide strip of wheat the length of each plot. In 1988, 1989, and 1991, we estimated weeds visually in corn plots just before harvest (0=no weeds, 10= dense weed population). In 1992, we counted the number of johnsongrass seed heads at harvest in two row middles per plot in corn, sorghum and soybean.

In 1987 and 1988, we measured N by digesting clover samples using a micro-Kjeldahl procedure (Bremner and Mulvaney, 1982), but thereafter we measured N and C with a Perkin-Elmer 2400 CHN Elemental Analyzer. We took corn ear leaf samples at anthesis from 1989 through 1992. Nitrogen was determined with the Elemental Analyzer and P and K were determined with a Perkin-Elmer Plasma II Emission Spectrometer. We took soil samples periodically, extracted them with Mehlich 3 extractant, and assayed the extractant for P (Olsen and Somers, 1982) and K (atomic absorption spectroscopy). Soil pH was determined on a 1:1 soil:water suspension. In April 1989, we grouped the plots into six categories based on soil pH, and applied dolomitic limestone at a rate designed to raise the pH to approximately 6.0.

Results

Green manures

Figure 1 shows crimson and red clover biomass just before killing by tillage or herbicides in the spring. In 1986, red clover biomass had accumulated only since the previous autumn seeding, whereas in later years the biomass was the autumn and winter regrowth of red clover managed for hay the previous spring and summer. Thus the 1986 data suggest that crimson clover is better than red clover as a fall-planted green manure. The method of planting crimson clover was dictated by the preceding crop. The combination of planting method and preceding crop had little effect on biomass accumulation each year. Overseeding into soybeans was poorer than drilling in 1988 and 1992, but better in 1991. Autumn and winter regrowth of red clover previously managed as hay was comparable to drilled crimson clover in 2 of the 5 years. Natural reseeding was al-

Table 4. Planting dates, cultivars, seeding rates, rotary hoeings and cultivations.

	1986	1987	1988	1989	1990	1991	1992
Corn							
Planting date							
CMP (April)	12	14	17	25[1]	12	19	17
RCI (May)	5	8	Apr. 29	20[1]	1	25[2]	1
Cultivar (DeKalb)							
CMP	789	789	789	789	689	689	689
RCI	689	689	689	689	689	689	689
Seeding rate (1000/ha)	55	62	66	74	74	74	55
Rotary hoeings (RCI)	0	0	0	0	0	2	1
Cultivations							
CMP	0	0	2	0	0	0	0
RCI	2	2	2	1	2	3	3
Sorghum (CMP and RCI)							
Planting date (June)	13	27	15	28	21	26	25
Cultivar	Funks 1516BR				DeKalb DK 64BR	Savannah 5	
Seeding rate (1000/ha)	124						
Rotary hoeings							
CMP	0	0	0	0	0	1	1
RCI	0	0	0	0	0	1	1
Cultivations							
CMP	0	1	1	2	1	2	2
RCI	2	2	1	2	1	2	2
Soybean (CMP and RCI)							
Planting date (June)	13	27	15	19	19	25	24
Cultivar	Deltapine 417						
Seeding rate (1000/ha)	124						
Rotary hoeings (RCI)	0	0	0	0	0	1	1
Cultivations (RCI)	2	3	3	2	2	3	3
Wheat (CMP and RCI)							
Planting date (Oct)	23	30	26	23	Nov. 6	21	9
Cultivar	Coker 916			Coker 983			Coker 916
Seeding rate (kg/ha)	70	70	140	90	70	70	200

[1] Planting was delayed in 1989 because of excessive rain in April.
[2] A long dry period followed the first planting date so late planting was delayed until after a rain event large enough to supply soil moisture sufficient for seed germination (see Fig. 2).

ways comparable to drilling. Our values of biomass with natural reseeding were greater than the those reported by Touchton et al. (1982) for 'Dixie' crimson clover naturally reseeded after grain sorghum in Georgia (3200 to 4100 kg/ha). Biomass of drilled crimson clover was within the range (3500 to 9200 kg/ha) reported by Hargrove (1986) for 'Tibbee' no-till drilled after grain sorghum in Georgia.

Low accumulation of biomass in 1989 was due to severe winterkill. In January, air temperature was 20 to 24°C for a week, which stimulated clover growth. Subsequent temperatures below 0°C and an ice storm killed a large fraction of the clover stand. Prolonged rain in April (Fig. 2) delayed clover plowing by about 11 days (Table 4), but even this extended growing period did not allow biomass to accumulate to levels measured in the other years.

Ryegrass infestation became progressively worse after 1989, so in 1992 biomass was separated into clover and ryegrass. Essentially no ryegrass was found in clover drilled the previous fall, but up to 50% of the biomass in the overseeded or naturally reseeded treatments was ryegrass (Fig. 1).

Graphs of N accumulation in the biomass are similar to graphs of biomass through 1989 (Fig. 1). During 1990 to 1992, biomass production remained high, but because of increasing infestation by ryegrass, N accumulation was lower than in previous years. In 1988, treatments significantly affected N accumulation; the differences generally reflected differences in biomass. The same pattern was noted in 1992, except with naturally reseeded clover. Biomass production in this treatment was significantly greater than with drilled clover, but N accumulation was signifi-

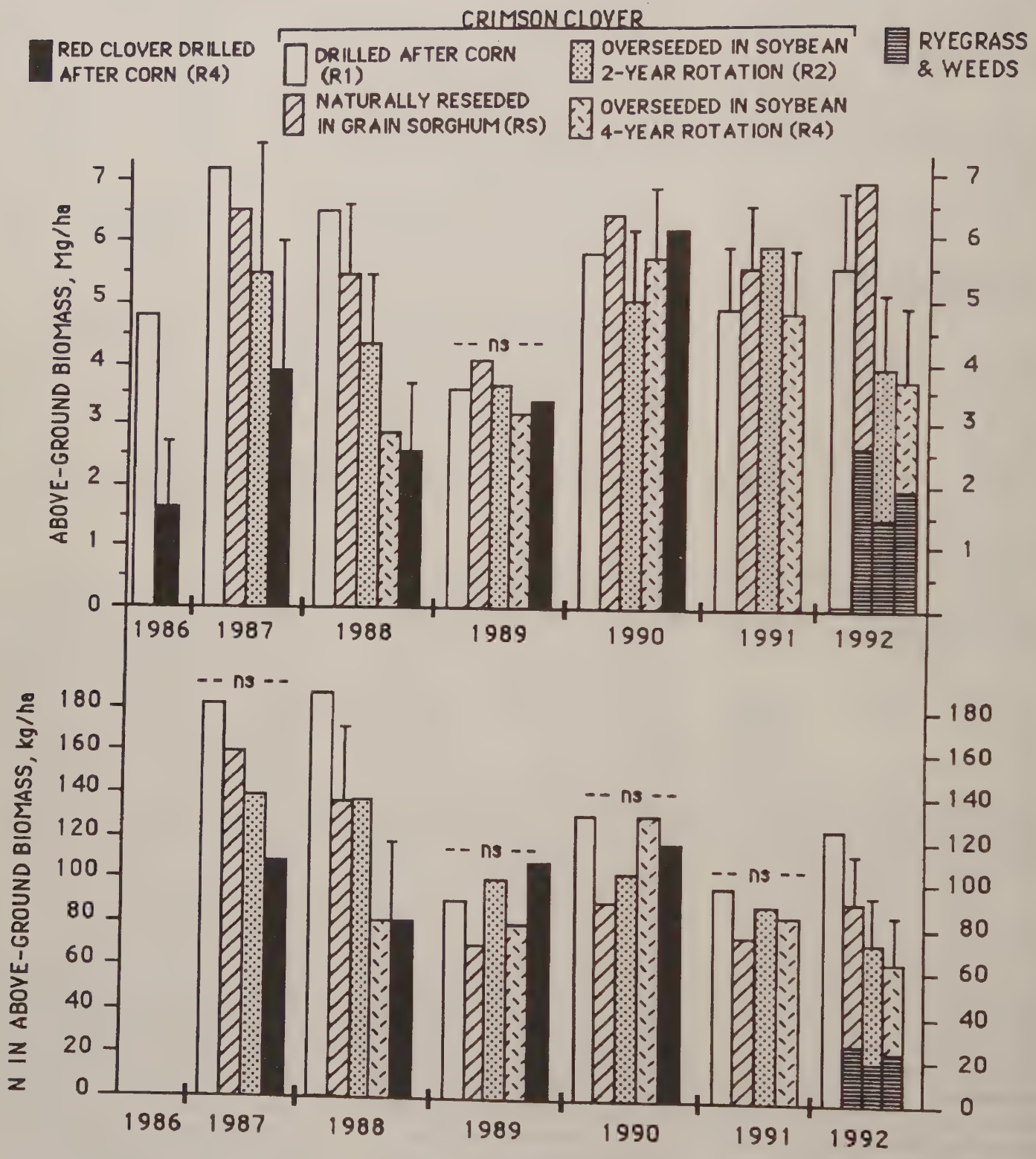

Figure 1. Above-ground biomass and N accumulation in crimson and red clover at late bloom stage. Biomass and N include contribution from winter weeds. Increasing infestation of ryegrass in 1990 and 1991 prompted reporting biomass and N from clover and ryegrass separately in 1992. Error bars indicate least significant difference at the 10% probability level. 'ns' indicates no significant difference.

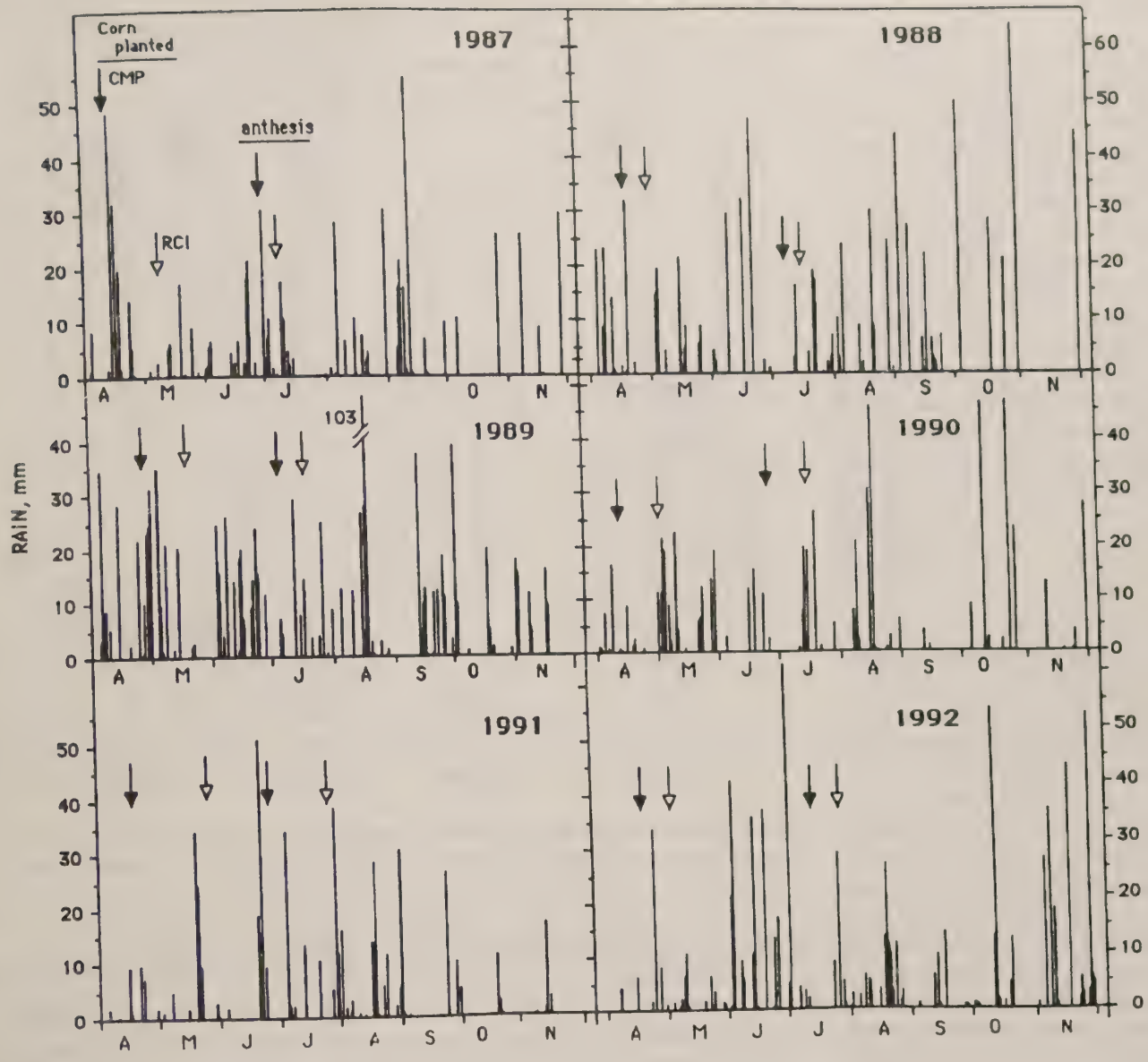

Fig. 2. Rain during the growing seasons. Arrows indicate dates of planting and median dates of anthesis.

cantly lower. The influx of ryegrass not only reduced total N accumulation but also reduced N availability because of the higher C/N ratio in ryegrass (36 vs. 23 in clover). In the previously cited Georgia studies with crimson clover, annual N accumulation was 62 to 76 kg/ha with naturally reseeded 'Dixie' (Touchton et al., 1982), and 92 to 220 kg N/ha with no-till planted 'Tibbee' (Hargrove, 1986).

If the system depends on winter legumes as the sole source of N for subsequent crops, one must be aware of the fluctuation in N supplied by green manures each year. Over the 7 years of this study, N supplied by crimson clover drilled after corn harvest ranged from 90 to 180 kg N/ha. Ranges for other clover treatments were: 70 to 160 for crimson clover naturally reseeded in grain sorghum, 65 to 140 for crimson clover overseeded in soybean, and 80 to 135 for red clover.

The 4-year rotation was changed to a 3-year rotation so that a legume would precede wheat and supply more N than in the 4-year rotation (see Tables 1 and 3). In the first year (1990), regrowth of red clover (and johnsongrass) after the last hay harvest (19 Sept. to 23 Oct.) was low, and only 10 kg N/ha was supplied by the clover (Fig. 3). Regrowth was not much better the next year, so alfalfa was harvested from an adjacent field and used to supplement the red clover. The clover supplied 27 kg N/ha, the alfalfa 80 kg N/ha. In 1992, regrowth was greater than in previous years, but most of the biomass was johnsongrass. The biomass contained about 45 kg N/ha. Effect of management on biomass and N was not significant.

Soil fertility

Mehlich 3-extractable soil P and K were variable across the experimental area (Table 5). Median concentrations were considerably above the medium fertility range used by the Agronomic Division of the North Carolina Department of Agriculture. Extractable P was not affected significantly by treatments (data not shown). In 1988 and 1992, significant treatment differences were found for K, but no meaningful trends were observed. Given the wide variation in extractable P and K across the area because of textural differences and fertilizer application for many years before this study, the lack of significant or meaningful differences was expected.

Corn

Rain was limited during anthesis or grain fill periods for corn during 1986-1988 and in 1990 (Fig. 2). Consequently, grain yields were low (less than 3000 kg/ha, Fig. 4) and although treatment effects were statistically significant, they may not have much practical meaning. However, we noted some overall trends. There was no response to fertilizer N in these years, so the data for CMP treatments are averaged over N rates. Yields in rotations were not different from yields in monoculture with RCI in any year, but yields with CMP were higher in the 2-year rotation than in monoculture in 1987 and 1990. Except in 1987, yields in all treatments were generally less than the county average (Watson, 1986-1990; Wayne Batton, County agricultural extension agent, personal communication, 1991). In paired-field comparisons of corn grown conventionally and organically (no pesticides or commercial fertilizer), Lockeretz et al. (1980) found conventional yields tended to be higher than organic yields when growing conditions were good but lower when conditions were adverse. In the dry years of the current study, CMP yields were generally higher than RCI yields (Fig. 4).

Rain was plentiful and well distributed during the spring and summer of 1989, and was adequate during the summer of 1991 and 1992 (Fig. 2). Corn yields during these 3 years are discussed below.

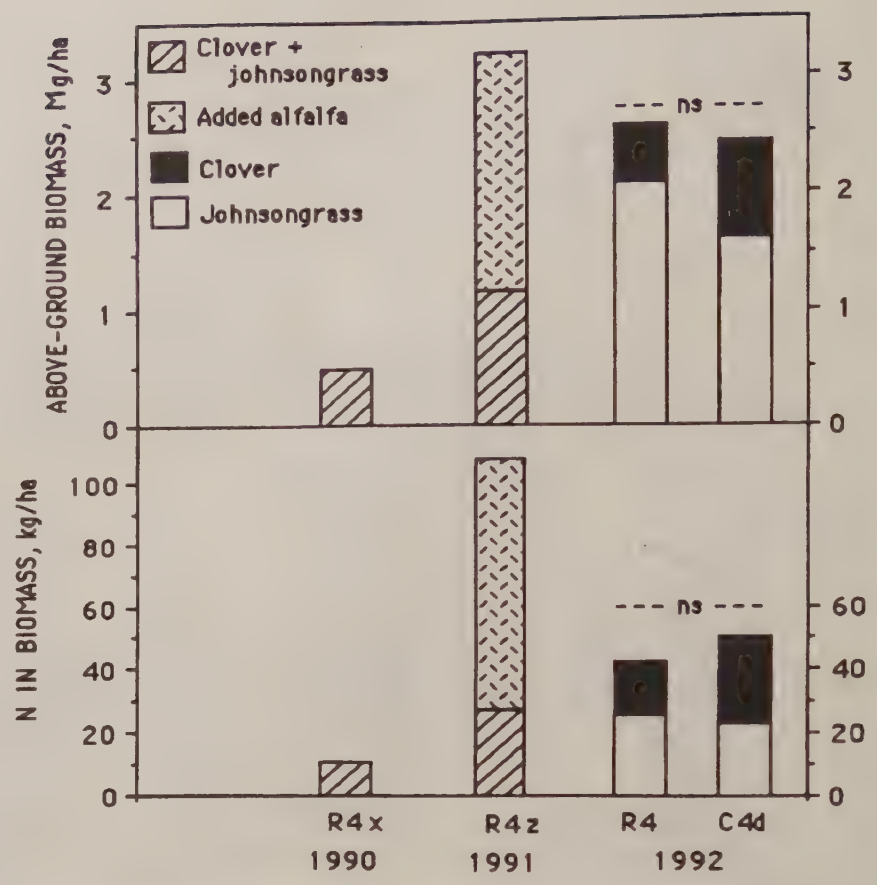

Fig. 3. Above-ground biomass and N accumulation in red clover and weed regrowth from date of last hay harvest until date of plowing and planting wheat.

Table 5. Mehlich 3-extractable soil P and K (mg/dm^3)

	Medium fertility range[1]	Year	Lowest	Median	Highest
P	31-60	1988	14	111	506
		1989	20	120	697
		1992	12	105	473
K	52-100	1988	124	266	615
		1989	108	228	464
		1992	96	184	374

[1] Yield response to P or K fertilizer would be small in this fertility range. No response would be expected at higher concentrations.

Yields with current management practices. In 1989, the corn crop was preceded by wheat-soybean-fallow in the 2-year rotation, and by red clover hay/green manure in the 4(3)-year rotation (Table 1). This difference in previous crops resulted in a significantly greater yield at all N rates in the 4(3)-year rotation compared with the 2-year rotation (Fig. 5). However, yields in the 2-year rotation differed significantly from yields of continuous corn at the 0 N rate only. Response to N fertilizer peaked at 105 kg/ha in the continuous system, 79 kg/ha in the 2-year rotation, and 52 kg/ha in the 4(3)-year rotation.

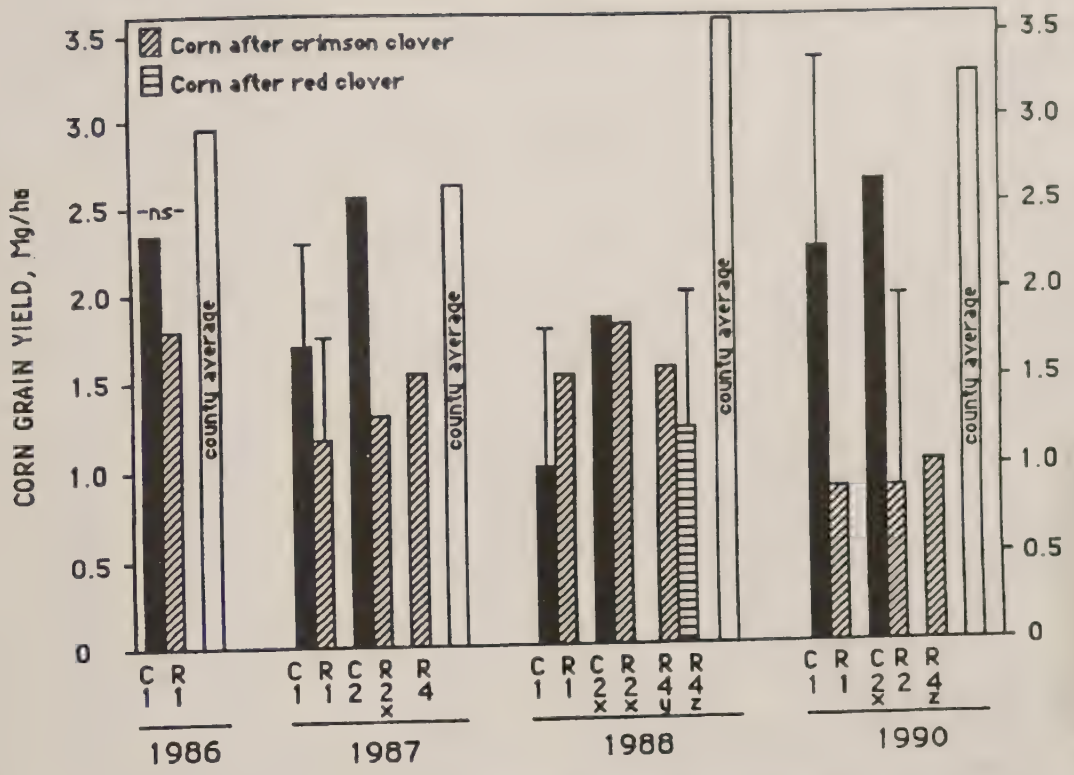

Fig. 4. Effect of crop sequence and management system on corn yield during drought years. Significant differences indicated as in Figure 1. Data in CMP treatments are averaged over fertilizer N rates.

The 1991 corn crop was preceded by wheat-soybean-fallow in both the 2-year and 4(3)-year rotations (Table 1). Thus, yield differences between these two rotations in 1991 were due to the residual effect of red clover hay/green manure versus wheat-soybean-fallow in 1988-1989. At 52 kg N/ha, yield was significantly higher in the 4(3)-year rotation, but differences were not significant at higher N rates because the 2-year rotation continued to respond to N while the 4(3)-year rotation did not (Fig. 5). The 4(3)-year rotation was superior to continuous corn at low N rates, but continuous corn responded to N such that yields were not different by an N rate of 105 kg/ha. The 2-year rotation responded to N at a greater rate than did continuous corn, and at 105 kg N/ha, yield was significantly higher in the 2-year rotation. In contrast to the 1989 results, only in the 4(3)-year rotation did N response peak within the range of applied N (at 52 kg/ha). In 1992, continuous corn did not respond to N rates above 70 kg/ha. Yield was significantly higher in the 2-year rotation than in monoculture.

The higher yields in rotations than in continuous corn were due in part to N released from residue of previous legume crops. However, this N contribution did not account for all the yield response to rotations. In 1989, for example, red clover green manure supplied 110 kg N/ha in the 4(3)-year rotation. With no additional N from fertilizer, corn grain yield was 5700 kg/ha (Fig. 5). With continuous corn, 90 kg fertilizer N/ha was required for a yield of 5700 kg/ha. Adding an additional 35 kg N/ha increased the yield of continuous corn by 500 kg/ha, but yield in the 4(3)-year rotation increased by 1900 kg/ha. Thus the yield response to rotation included more than the effect of legume N. Another way to look at the rotation effect is to compare the difference in the effect of the 2-year and 4(3)-year rotations at the 0 N rate in 1989. The yield increase above continuous corn was 1500 kg/ha for the 2-year rotations (57 kg N/ha from soybean residue), and 5600 kg/ha for the 4(3)-year rotation (110 kg N/ha from red clover green manure). Nitrogen contributed by soybean residue was estimated from the ratio of N in residue to grain yield calculated from the data of Hanway and Weber (1971a,b). Similarly, comparing the two rotations at the 52-kg N rate in 1991 shows a much higher yield in the 4(3)-year rotation (50 kg N/ha from soybean residue) than in the 2-year rotation (57 kg N/ha from soybean residue).

One factor other than legume-supplied N may have been soil moisture in 1989. Although rain generally was plentiful, the thick mulch formed by the dead red clover may have been more effective than corn or soybean residue in increasing infiltration and conserving moisture during short dry periods.

Yields with reduced chemical inputs. In 1989, yields in RCI treatments were lower than in the CMP 4(3)-year rotation at the 0 N rate (i.e., with N supplied by red clover only) and not significantly different from the 0 N rate in the CMP monoculture and 2-year rotation (Fig. 5). With RCI

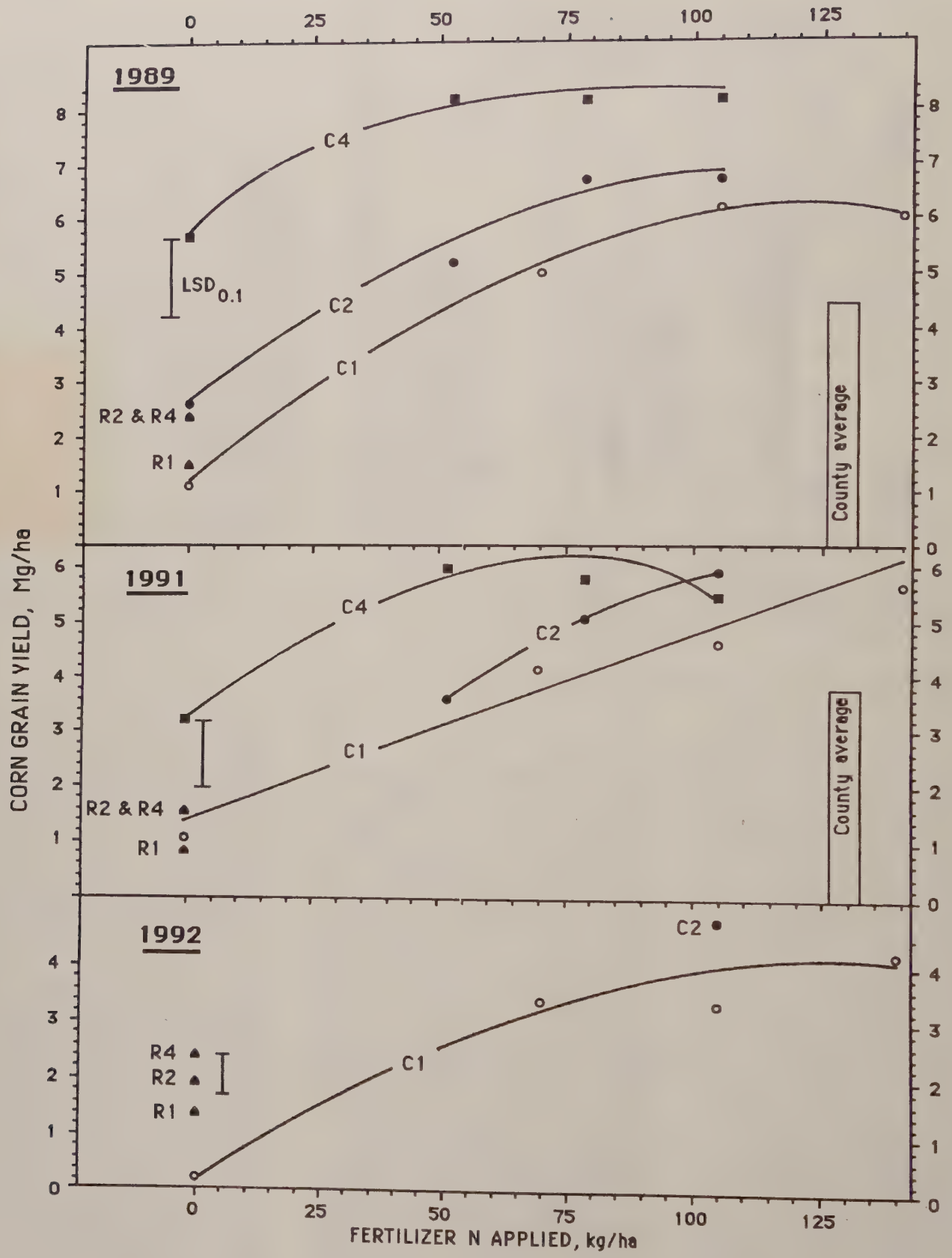

Fig. 5. Effect of crop sequence, management system, and N fertilizer on corn grain yield.

management, the effect of rotation was not significant. In 1991, yields were low in all treatments receiving RCI management (Fig. 5), primarily because of heavy infestation of johnsongrass. In 1992, yields with RCI management were significantly higher than yield of continuous corn receiving no N in the CMP management system. However, they were significantly lower than CMP treatments receiving fertilizer N. This was the first time the rotation effect was significant with RCI management.

Weed competition. Lower yields with RCI management were due in part to weed competition, primarily from johnsongrass (Fig. 6). Control was good in the CMP treatments because post emergent application of nicosulfuron essentially eliminated johnsongrass in 2- and 4(3)-year rotations and controlled it well in continuous corn where N fertility levels were adequate (≥70 kg N/ha). Nicosulfuron was banded over the row at second cultivation in all RCI treatments in 1992. Control was good in the 2- and 4(3)-year rotations but not in monoculture.

Nutrient concentration in corn ear leaves. The recommended (highest) fertilizer N rate with CMP resulted in higher ear leaf N concentrations than did use of legumes with RCI management (Fig. 7). The rotation effect was noted with CMP, where N increased significantly from the 2-year to the 4(3)-year rotation in 1989, and from continuous corn to the 2-year rotation in 1990. With legume sources of N, the rotation effect was noted only in 1990 (4(3)-year > continuous). Concentrations with CMP generally were in the range sufficient for good corn production, but with legume N sources they were consistently below the minimum sufficiency concentration.

Generally, all treatments resulted in ear leaf P concentrations that were in the sufficiency range (Fig. 7). Often, P concentration was higher with RCI than with CMP. The difference was dramatic in 1992. We did not measure corn biomass when ear leaf samples were taken, so we could not determine if the lower concentration with CMP occurred because P was diluted by the greater biomass production. The rotation effect was not significant with CMP, but RCI resulted in higher P in the 4(3)-year rotation than in monoculture every year except 1992.

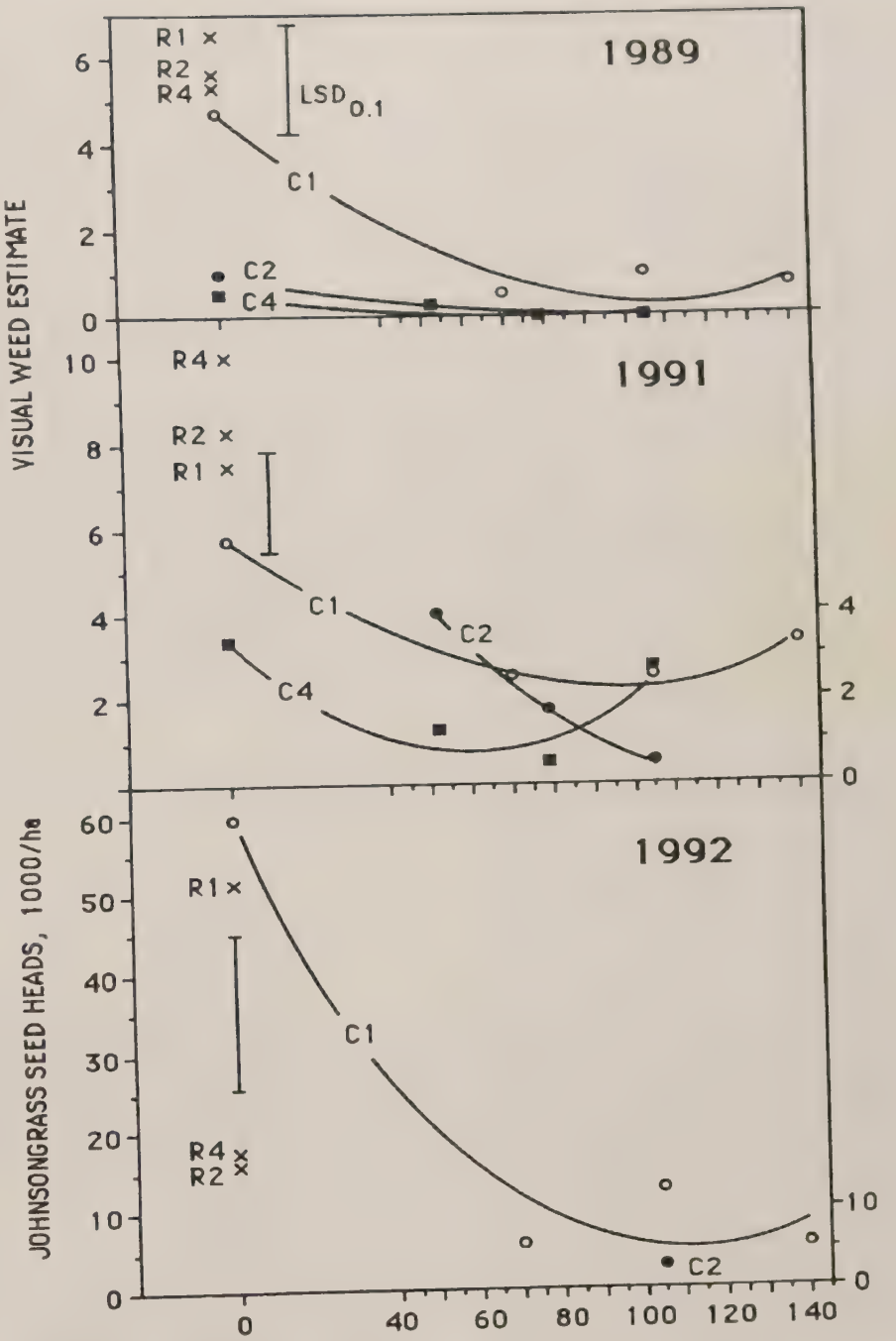

Fig. 6. Effect of crop sequence and fertilizer N rate on visual estimate of weeds (1989, 1991) and number of johnsongrass seed heads in corn at harvest. Nicosulfuron herbicide banded over rows at second cultivation in RCI treatments in 1992.

In 1989, leaf K concentrations were significantly higher in CMP rotations compared with all RCI treatments. Treatment differences were small or not statistically significant in other years. All treatments resulted in K concentrations in the sufficiency range.

Population. Treatments had little effect on corn population at harvest in 1988, but in 1989 and 1990, populations were significantly lower with RCI than with CMP (Fig. 8). One reason for this difference may be the porous seedbed in the RCI treatments. To accumulate as much N as pos-

sible in the crimson clover and yet plant corn early, the clover was plowed and disked and then the corn planted as soon as possible. The undecomposed clover residue resulted in a porous seedbed and poor seed-soil contact. Another factor affecting population was the interaction between planting date and rain distribution. In 1988, approximately 30 mm of rain occurred after each planting date (Fig. 2), but in 1989, rain was plentiful before and after planting the CMP treatments, but was low after planting the RCI treatments. The planting date × rain distribution interaction was not a factor in 1990, since appreciable rain occurred after the RCI treatments were planted.

In 1991, rain in April was low (Fig. 2), but soil moisture was adequate for planting the CMP treatments (no-till). However, because of the coarse seedbed, and because moisture was lower in the RCI treatments from transpiration by crimson clover, we delayed planting until adequate rain occurred. Consequently, treatments did not affect population in 1991. In 1992, we attached disks to the front of the planter to move some plant residue and loose soil aside and form a wide, shallow furrow (about 5 cm deep) into which the seeds were planted. Population differences due to treatments were small.

Seeding rates were increased from 55,000 seeds/ha in 1986 to 74,000 in 1989 (Table 4). We did this to overcome the poor rate of establishment and subsequent low population in the RCI treatments, as discussed above. The negative effect of this increase was excessive population in the CMP treatments (1989 - 1991, Fig. 8) and in the RCI treatments when soil moisture conditions were optimal (1991, Fig. 8). With these excessive populations, many plants failed to form ears. Therefore they competed with the productive plants just as weeds would have competed. Using the trash-clearing disks ahead of the planter in the RCI treatments in 1992 produced a firm seedbed and allowed the seeding rate to be reduced to 55,000 seeds/ha.

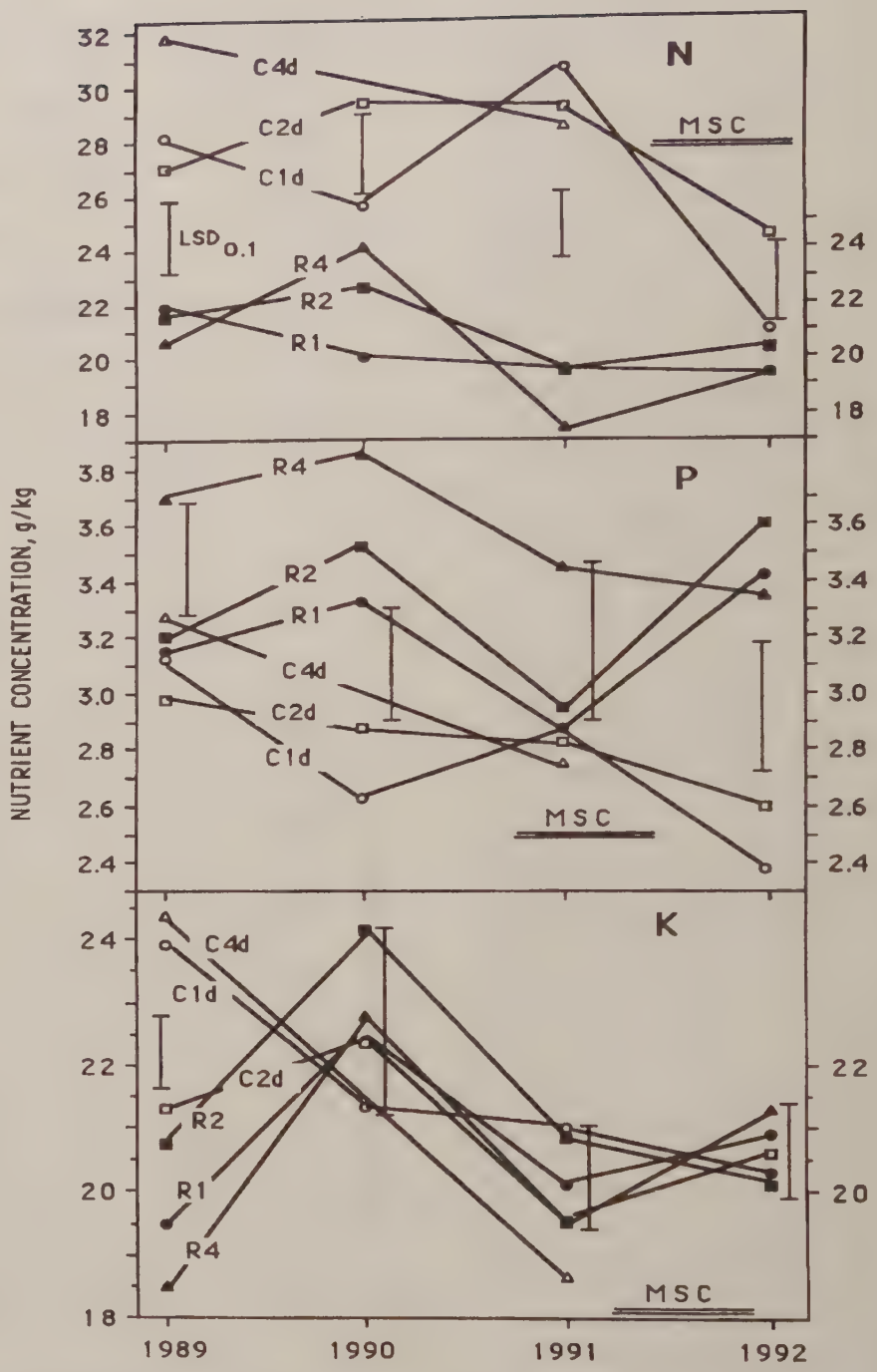

Fig. 7. Effect of treatments on N, P, and K concentrations in corn ear leaf at anthesis. MSC is the minimum sufficiency concentration for corn production.

Factors affecting corn yield. Table 6 presents the coefficients of correlation between corn yield and various parameters. Yield was not well correlated with population. The most frequent correlation was between yield and weed estimates. In years when rain was adequate, CMP yields were correlated with fertilizer N, and with N supplied by red clover in 1989. In contrast, yields with RCI were not correlated with N supplied by crimson or red clover. Correlation between yield and nutrient content of ear leaves at anthesis was more pronounced with CMP than with RCI. The negative relationship between yield and P may show that P is diluted as more biomass accumulates.

Correlations between yield and soil properties were significant only in 1992 with RCI. Figure 9 shows the relationship between Mehlich 3 P and yield for the RCI

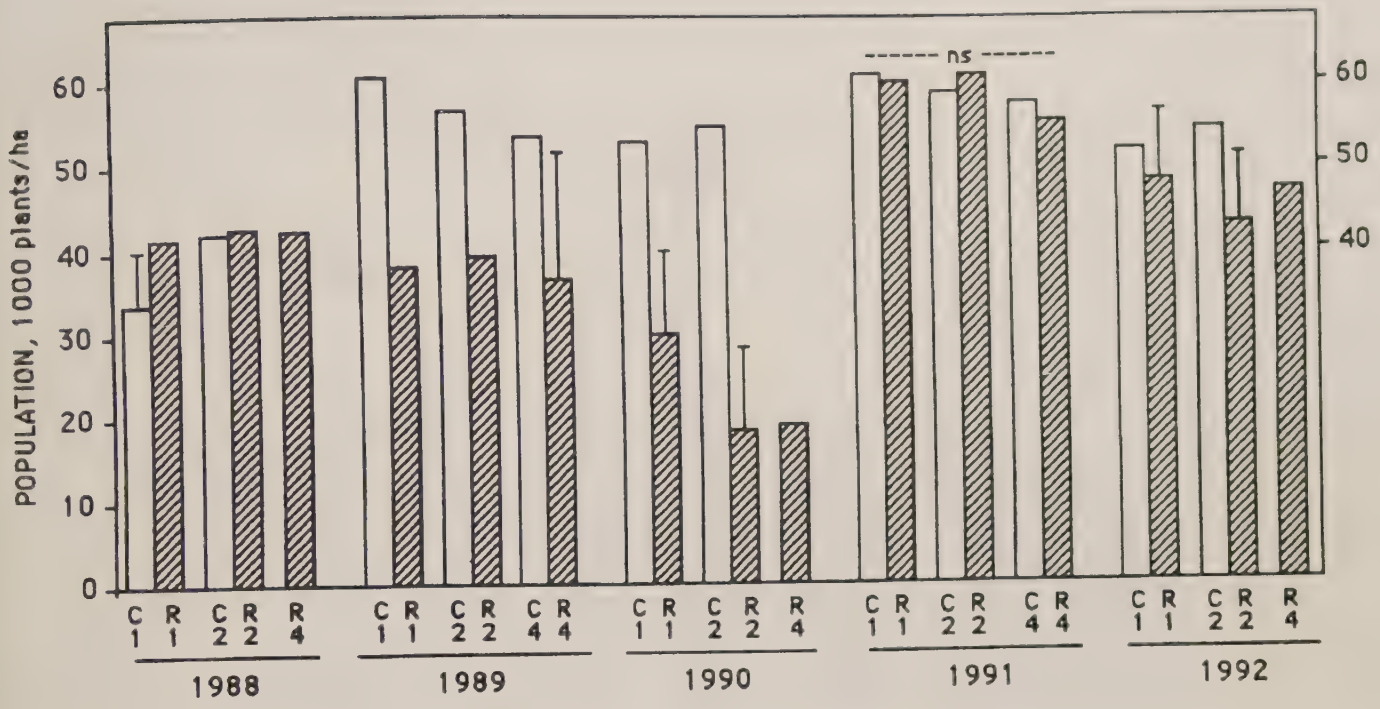

Fig. 8. Effect of treatments on corn population at harvest. Data for CMP treatments is averaged over N rates. Significant differences indicated as in Figure 1.

Table 6. Correlation coefficients for corn yield with various parameters.[1]

Year	Population	Weeds	N supplied	Ear leaf			Soil		
				N	P	K	P	K	pH
Current Management Practices									
1987	—	-0.35	ns	—	—	—	—	—	—
1988	ns	-0.78	ns	—	—	—	ns	ns	ns
1989	ns	-0.67	0.47[2]	0.78	-0.41	0.34	ns	ns	ns
1990	—	ns	ns	ns	ns	ns	—	—	—
1991	ns	-0.46	0.66	0.81	ns	0.62	—	—	—
1992	ns	-0.83	0.37	0.87	-0.69	0.45	ns	ns	ns
Reduced Chemical Inputs									
1987	—	ns	ns	—	—	—	—	—	—
1988	ns	-0.75	ns	ns	ns	ns	—	—	—
1989	0.60	-0.59	ns	0.46	-0.57	ns	ns	ns	ns
1990	—	ns	ns	ns	ns	ns	—	—	—
1991	ns	ns	ns	ns	ns	ns	—	—	—
1992	ns	-0.71	ns	ns	ns	ns	0.78	-0.54	0.83

[1] All correlations significant at the 10% level of probability unless indicated by "ns". Where no coefficient is shown, the variable was not measured.

[2] Correlation coefficient between corn yield and N supplied by red clover green manure is 0.33.

treatments and for the CMP treatments receiving N fertilizer (treatment C1a was not included). With CMP, yield was not related to soil P, but with RCI, yield increased with an increase in soil P. Response to P is generally greater when plants are stressed in some way. Here, the weed pressure was much greater in RCI than in CMP (Fig. 6), available N was lower (e.g.,

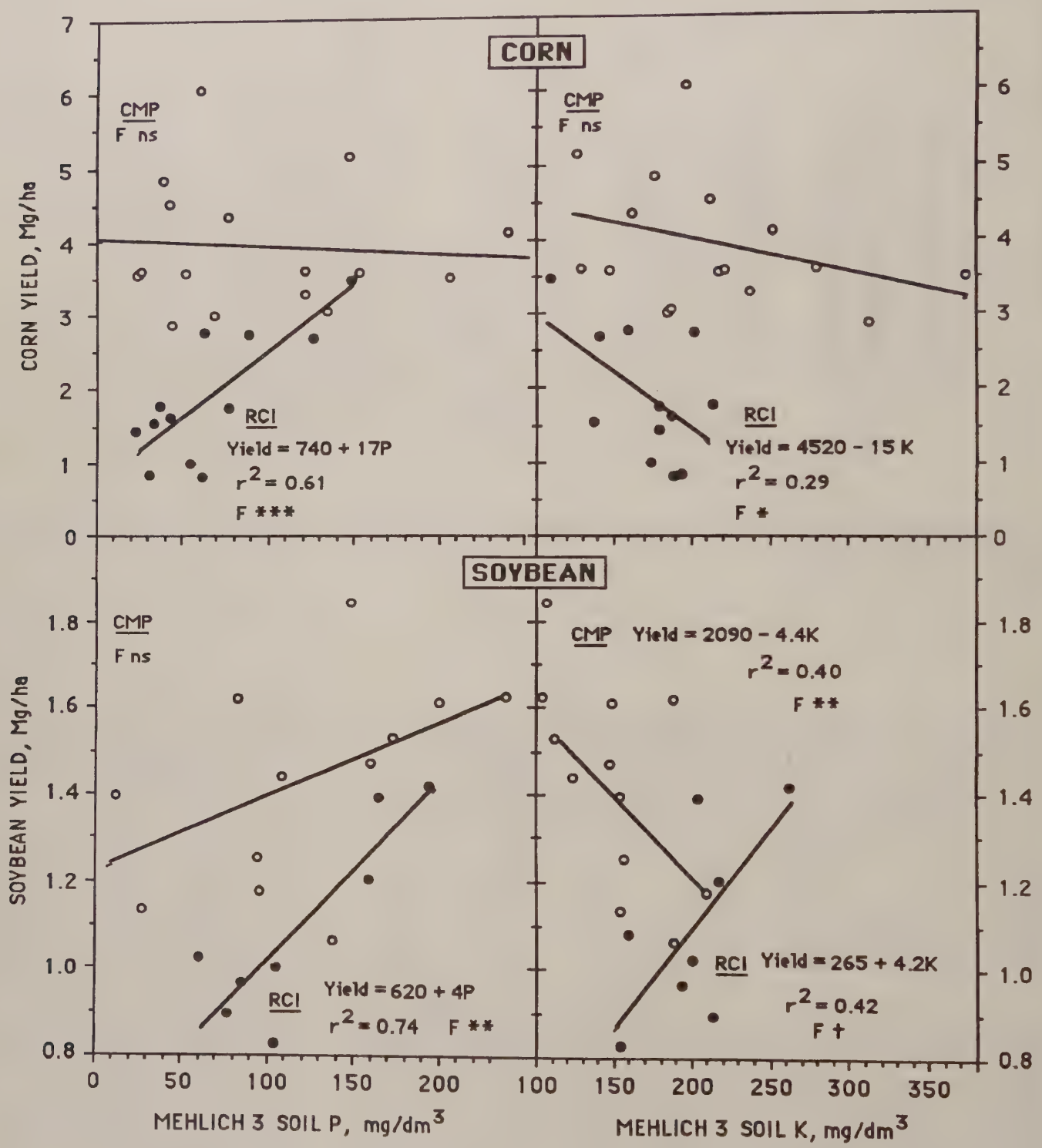

Fig. 9. Relationship between Mehlich 3 soil P and K and yield of corn and soybean, 1992. CMP data do not include the zero rate of N fertilizer. Regression models were significant at the 10% (+), 5% (*), 1% (**), or 0.1% (***) level of probability.

earleaf N, Fig. 7), and the root system was smaller (Crozier, 1992). The correlation between yield and pH was a result of correlation between P availability and pH. Although yield was correlated with soil K, the coefficient was low.

Soybean

Nitrogen was not applied to soybean except as discussed below, and soybean yields with CMP were not significantly affected by the N rate applied to previous wheat or corn crops. Consequently, the data in Figure 10 are averaged over these previous N rates. For example, the yield for the 2-year CMP rotation is the average of C2a - C2d in even years (see Table 1). Yields in the 2-year rotation were not affected by management system in 1986, 1988, and 1989, but CMP was higher in the

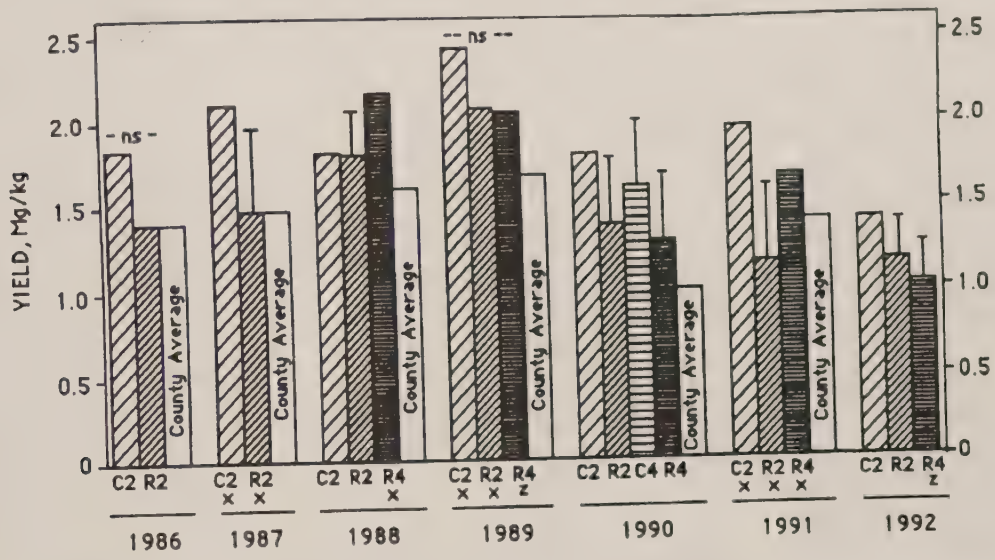

Fig. 10. Effect of management system and crop sequence on soybean yield. Significant differences indicated as in Figure 1. Data for C2 is average of C2a-C2d (see Table 1).

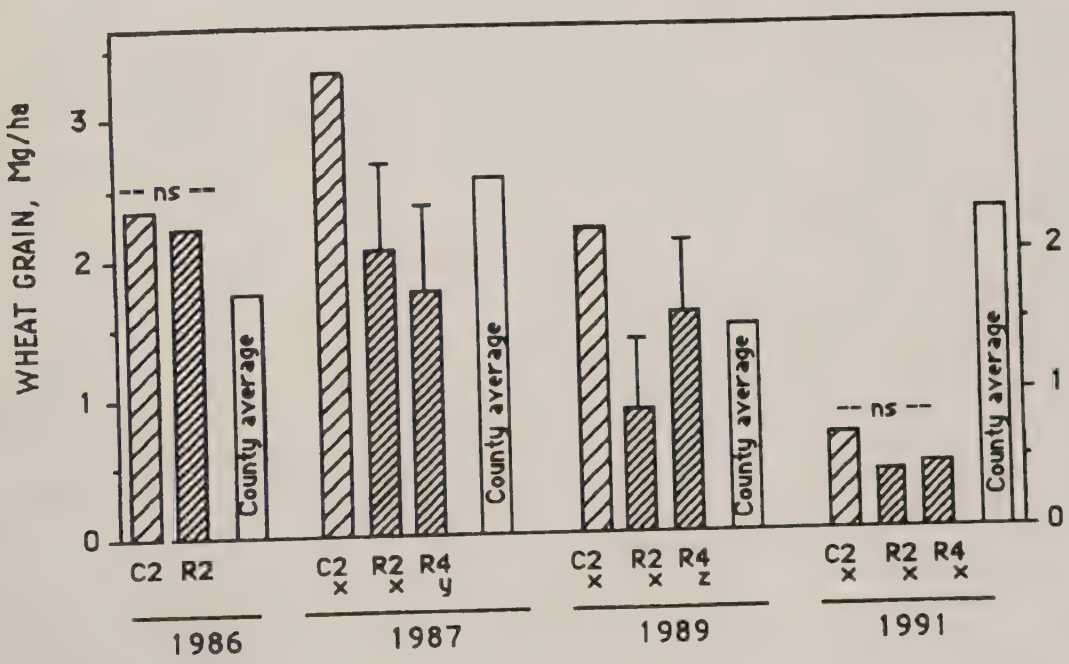

Fig. 11. Effect of management system and crop sequence on wheat yield. Years shown are those in which CMP treatments received only one rate of N fertilizer and 1986 when wheat did not respond to N fertilizer (data averaged over N rate). Significant differences indicated as in Figure 1.

other 4 years (Fig. 10). Management system was not significant in the 4(3)-year rotation (1990). Within RCI systems, the 4(3)-year rotation was superior to the 2-year rotation in 1988 and 1991. All yields generally were above county averages. Since no fertilizer was applied to soybean, yield differences between the CMP and RCI systems were due mainly to the comparative effectiveness of chemical and mechanical weed control. In 1990 the amount of N applied to previous corn and wheat crops affected soybean yields. Yields were not different among the three rates of applied N, but where no N had been applied, yields were significantly lower: 1300 kg/ha vs. 1800 kg/ha (averaged over the non-zero N rates) in the 2-year rotation, and 1050 vs. 1600 in the 4(3)-year rotation. This effect of previous N additions was not significant in 1988.

Johnsongrass was the predominant weed in soybean. A count of seed heads just before harvest in 1992 showed a range of 1400 to 7100 heads per hectare, but because of the large variation among replications (CV=76%), no significant effect of treatments was found.

The relationship between soybean yields and soil P and K was positive with RCI, although the r^2 value was low for K (Fig. 9). Yields with CMP were not significantly related to soil P but were negatively related to soil K. The r^2 value was low for K; the reason for the negative relationship was not apparent.

Wheat

Treatments did not affect wheat yields in 1986 (Fig. 11), probably because residual soil N after corn silage in 1985 was sufficient to mask the effect of N applied to wheat (yield for CMP is averaged over N rates). In 1987 and 1989, when only one N rate was used in the CMP system, CMP was better than RCI. The very low yield of all treatments in 1991 was due to heavy ryegrass infestation and possibly to a residual effect of the nicosulfuron herbicide applied to control johnsongrass in corn in the CMP treatments. In 1989 (Fig. 11) and 1988 and 1992 (Fig. 12) with RCI management, yields were higher in the 4(3)-year rotation than the 2-year rotation. In 1992, part of the higher yield in the longer rotation was due to the addition of alfalfa to simulate good regrowth of red clover after the last hay harvest (Fig. 3). Although alfalfa and red clover together contributed over 100 kg N/ha, wheat yield in R4 was lower than the yield in C2b, which received only 45 kg fertilizer N/ha.

Regression of wheat yield on fertilizer N rate in the CMP treatments was significant each year, but r^2 values ranged only from 0.43 to 0.49 (Fig. 12). Wheat responded well to N in 1988, but lower yields in 1990 were due in part to red clover competition in the 4(3)-year rotations. Red clover had been plowed or killed with a herbicide in 1989 before planting corn that preceded the wheat, but clover reestablished in many plots. Generally, CMP yields were comparable to or greater than the county average yields. Yields with RCI were comparable or lower. The dramatic

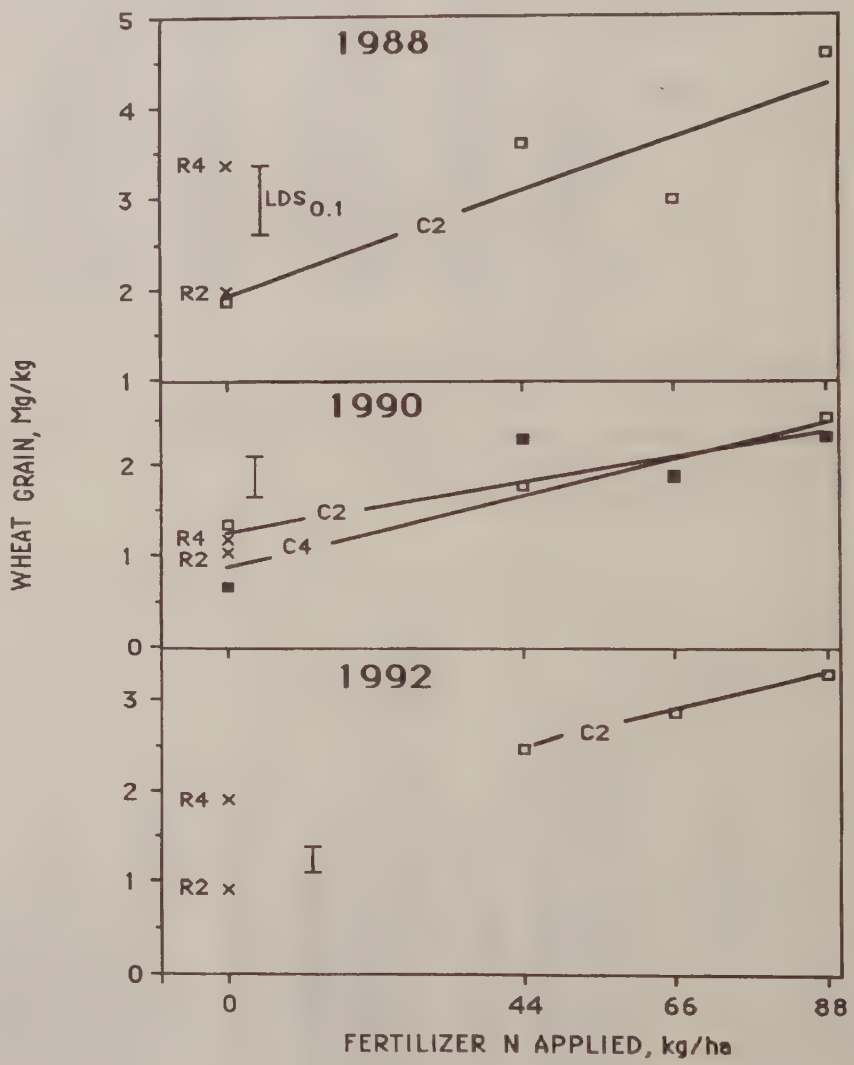

Fig. 12. Effect of management system, crop sequence, and fertilizer N on wheat yield. With CMP (no-till), the stand was poor in the fall of 1991, so CMP plots were tilled and wheat replanted.

improvement of yields in 1992 compared with 1991 was due in part to complete control of ryegrass by diclofop herbicide.

Insufficient N was the main reason that yields with RCI were lower than with CMP. Crimson and red clover grown the previous winter and spring did not supply sufficient N to corn and the following wheat crop. Another factor in 1992 was the high population of crimson clover in the wheat (data not shown). To reduce the cost of planting crimson clover, we conducted an auxiliary study in which we broadcast crimson clover at 6 kg/ha before drilling wheat in 1990. This rate produced a thin stand of clover that provided sufficient seed to produce a good stand of clover in soybean by the fall of 1991. This technique was used in the main experiment in Fall 1991 (Table 3). However, because of the germination of hard seed from previous years (a condition that did not occur in the auxiliary study) plus the clover from the planted seed, the clover population was high enough to compete with the wheat.

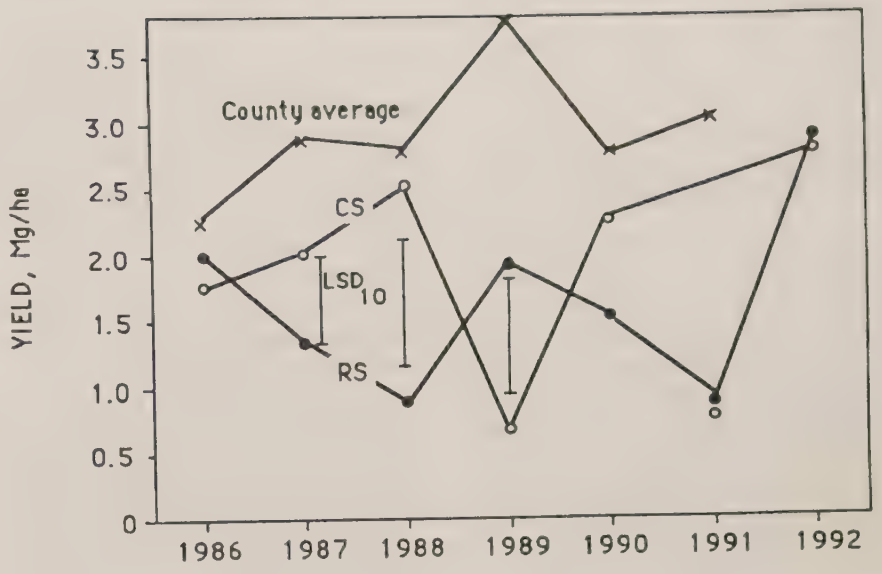

Fig. 13. Effect of management system on grain sorghum yield. Low yield of CS in 1989 was due to herbicide injury (see footnote, Table 2).

Grain sorghum

Generally, grain sorghum yields with CMP were comparable to or higher than yields with RCI (Fig. 13). The exception was in 1988, when the CMP treatment was damaged by herbicides. The low yield of both systems in 1991 was due to poor seedling emergence. Yields in the experiment were consistently lower than the county average.

Although naturally reseeding crimson clover in the sorghum treatment accumulated large quantities of biomass and N during 1986-1988 (Fig. 1), yields of RCI sorghum declined each year (Fig. 13), mainly due to increased johnsongrass infestation. In 1989, however, the plots were almost completely free of johnsongrass—although all the cultural practices were the same as in past years. Consequently, yield in the RCI treatment was comparable to yield in 1986. Yields in both treatments were probably reduced by an outbreak of Helminthosporium leaf spot blight that occurred after the second cultivation (Aug. 7). The reason for the almost complete absence of johnsongrass in 1989 was not apparent. Disease was not a likely cause, because johnsongrass was vigorous in corn plots adjacent to the sorghum plots. The increased rain in 1989 could have stimulated greater production of allelochemicals by microorganisms and increased leaching of allelochemicals into the soil. Four of the 8 plots have remained relatively free of johnsongrass, but broadleaf weeds have become more prevalent. The suppressive effect of sorghum was very evident in 1992: continuous corn (R1) contained 50,000 johnsongrass seed heads per ha, but continuous sorghum (RS) contained only 5,000/ha.

Red clover hay

Since all entry points are not included in the CMP 4(3)-year rotation, 1988 was the only year we could compare management systems for red clover. No fertilizer or pesticides were applied to the CMP clover, so the only management effects were residual effects of additions to previous crops. We found no difference from management system (Table 7). In 1988 the hay was predominantly red clover, but in the other years it contained a high proportion of ryegrass in the spring and johnsongrass in the summer. For example, hay regrowth plowed as green manure for wheat in 1992 was 70 to 80% johnsongrass (Fig. 3). Hay yields have been superior to the county average in 4 of 6 years.

Summary

Green manures. During the 7-year period, natural reseeding in grain sorghum produced as much or more clover biomass as planting with a drill after corn harvest. Aerial seeding into soybeans was comparable to drilling 4 of the 6 years. Annual weather conditions had the greatest effect on clover growth, with biomass and N varying by as much as twofold among years. An increasing infestation of annual ryegrass reduced clover biomass and N, but did not greatly affect total biomass. Infestation occurred mainly with natural reseeding and aerial seeding, techniques used to reduce seeding cost. There was evidence in 1992 that volunteer crimson clover may become a weed problem in wheat.

Corn. Rotating crops increased corn yield in the CMP treatments but not in RCI treatments. In the 4 dry years, corn yields were low (less than 3000 kg/ha), corn did not respond to fertilizer N, and yields with CMP generally were equal to or greater than with RCI. In the 3 years with adequate rain, yields in RCI treatments with crimson

Table 7. Red clover hay yield (kg/ha).[1]

Management system	1986	1987	1988	1989	1990	1991	1992
C4	—	—	5950a[2]	—	—	—	8320a
R4	4700	3260	5990a	6960	11,200	5400	9350a
County average, all hay	3580	4030	4030	4700	5600	6700	—

[1] In all years except 1988 hay was a mixture of red clover and ryegrass in the first cutting and red clover and johnsongrass in subsequent cuttings. Hay was essentially all red clover in 1988.
[2] In a given year, values followed by the same letter are not significantly different at the 10% level of probability.

and red clover were significantly lower than yields in CMP treatments receiving fertilizer N, probably because of johnsongrass competition and insufficient N.

Soybean. Soybean yield was higher with CMP in 4 of 7 years, and higher with RCI one year. With RCI, yield in the 4(3)-year rotation was higher than in the 2-year rotation in 2 of 4 years.

Wheat. Wheat yields were consistently higher with CMP than with RCI because RCI treatments lacked sufficient N. Yields were higher in the 4(3)-year rotation than in the 2-year rotation in 3 of 6 years with RCI and 1 of 2 years with CMP. Annual ryegrass became such a serious problem that a herbicide was used in all treatments in Fall 1991.

Sorghum. Grain sorghum yields were greater with CMP than with RCI. A dramatic decline in johnsongrass in sorghum was noted in 1989, and several plots remained almost free of johnsongrass through 1992.

Red clover hay. Treatments did not affect yield of red clover hay. Annual ryegrass made up a sizable fraction of the hay in the spring, and johnsongrass was abundant in the summer.

Management Decisions

Besides showing the results of the experiment, we thought it might be helpful to researchers contemplating similar studies to list some issues we faced and the decisions we made.

Treatment selection

In recent experiments on sustainable agriculture, herbicides are used at reduced rates instead of being eliminated, or they are used on an 'as needed' basis. However, when this experiment was being planned (1984-85), we believed that the RCI treatments should be practices useful to organic farmers, that is, they should receive no commercial fertilizer or pesticides. Although this extreme strategy appeared agronomically risky, we thought it should be tested. Perhaps we persisted too long in trying to make these treatments work, but we thought they should be continued long enough to determine if they were going through a transition period sometimes observed when converting from conventional to RCI management. Also, since the treatments were in place for several years, we believed that although they were not as productive as CMP treatments, it would be useful to learn their long-term effects on soil properties.

During a long-term experiment, improved crop varieties, pesticides, tillage equipment, and other production inputs become available. One must decide whether to use the new technology or to retain the original technology. We chose to use newer technology if it did not substantially change the crop sequences.

Weed control

The biggest problem in the experiment was controlling johnsongrass. It was present at the site before the experiment was started, but had been controlled satisfactorily with herbicides for several years in conventionally planted corn silage. We chose to use no-till planting in the CMP treatments to improve soil conservation. As a result, we had difficulty controlling johnsongrass in corn with the available herbicides. Control became so difficult that after 3 years we considered changing to conventional planting so that we could use more effective herbicides. However, nicosulfuron herbicide became available in 1989; therefore, we could continue with no-till planting.

In the RCI treatments, johnsongrass control was so difficult that after a few years, we considered suspending the RCI treatments for a year or more, using glyphosate (Roundup) to eliminate the johnsongrass, and then resuming the treatments. That way, we could learn if RCI would be successful on a site free of johnsongrass. However, we also reasoned that if RCI could be made to work on a site with johnsongrass, RCI would be much more widely applicable. Also, we did not want to interrupt the crop sequences, since they had been in place for several years. Therefore we continued with this treatment despite the serious johnsongrass problem. As we already noted, however, we began band application of herbicides in both corn and soybean in 1992. Similarly, we had to begin using diclofop to control ryegrass in wheat.

Additional treatments

As noted in the Methods section, we anticipated the need for adding treatments during the experimental period and made provisions to do so. These treatments included: CMP continuous corn with primary tillage (chisel plowing and disking); killing crimson clover and planting corn two weeks earlier than in the RCI treatments (i.e., at the same time CMP treatments were planted); applying fertilizer N to corn and wheat in RCI treatments; and planting corn into strips where crimson clover had been mechanically killed. This flexibility proved very useful; we will report the results in later publications.

Acknowledgments. We appreciate the technical assistance of Mark Barnes, Richard Gauger, Brian Foster and the staff at Research Unit 9. Partial funding of this project was supplied by the USDA Low-Input Sustainable Agriculture program.

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UPCOMING EVENTS

August 31-September 4, *Soil Management in Sustainable Agriculture* will be held at Wye College, University of London, Ashford, Kent, TN25 5AH, U.K.; contact Dr. H. Lee, fax: (0233-813320).

September 5-13, *International Conference on Integrated Resource Management for Sustainable Agriculture* will be held in Beijing, China; contact Dr. Li Xiaoyun, Center for Integrated Agricultural Development, Beijing Agricultural University, Beijing, 100094, PR China; phone 86-1-258-2337.

September 7-9, *Trade in Organic Products*, sponsored by International Federation of Organic Agriculture Movements, Organic Foods Production Association of North America, and New Hope Communications, will be held in Baltimore, MD; events include an organic trade fair and an organic dinner; contact Katherine DiMatteo, OFPANA, (413)774-7511, or Steven Hoffman, New Hope, (303)939-8440.

September 9, *Thompson On-Farm Research Field Day* will be held, with field tours and demonstrations; call Dick and Sharon Thompson, 2035 190th St., Boone, IA 50036; (515)432-1560.

September 18, *Northeast Organic Farming Association/New Jersey's 3rd Organic Country Fair* will be held in Pennington, NJ; contact NOFA/NJ, 31 Titus Mill Road, Pennington, NJ 08534; (609)737-6848.

Biodynamic Farming Shows Promise in New Zealand, Research Finds

Biodynamic farming practices and systems in New Zealand show promise in mitigating some of the detrimental effects of chemical-dependent, conventional agriculture on the environment, according to a research report published recently in *Science*. In a study done in New Zealand, the physical, biological, and chemical soil properties and economic profitability of 16 adjacent, commercial biodynamic and conventional farms were compared. "The biodynamic farms in the study had better soil quality than the neighboring conventional farms and were just as financially viable on a per hectare basis," the article said. Authors were John P. Reganold, Alan S. Palmer, James C. Lockhard, and A. Neil Macgregor.

Support in New England for certification and labelling of produce grown using integrated pest management

Craig S. Hollingsworth, M.J. Paschall, Nancy L. Cohen, and William M. Coli

Abstract. *We surveyed a total of 549 Cooperative Extension clientele (consumers), farmstand owners, and food industry representatives in New England to assess the potential for certification and labelling of produce grown using integrated pest management (IPM). The survey elicited self-reported knowledge of IPM, perceptions of current pesticide use and IPM, and attitudes toward certification and labelling of produce as "IPM-Grown." The respondents expressed widespread support for certification and labelling of produce grown using IPM. Potential barriers to the marketing of IPM-labelled produce were also revealed. The survey showed the need for education to inform the public about pest management in agriculture and to build confidence in the safety of our food supply.*

Key words: IPM-labelled produce, alternative pest control, consumer perceptions

The Status of Integrated Pest Management

The heavy use of pesticides in agriculture has alerted researchers, legislators, farmstand owners, and the public to the need for alternative pest control methods. Public concerns about how pesticides affect environmental quality and food safety have increased steadily over the past several decades (Sachs et al., 1987).

One alternative to conventional pest control is integrated pest management (IPM), an interdisciplinary approach to farming that combines environmental and economic factors into pest control decision-making and incorporates biological, physical, and chemical methods of pest suppression. Prokopy (1990) describes how IPM can be viewed over a continuum, with early levels focusing on control of single pest groups, and more advanced levels incorporating other farm practices and marketing aspects. In Massachusetts, IPM has reduced pesticide use on apples, strawberries, cranberries, corn, and potatoes by as much as 40 to 60% (Coli, 1990). Guidelines to define and evaluate IPM practices have been developed for several cropping situations (e.g., Hollingsworth et al., 1992a,b).

Farmers adopting IPM have gained several advantages. A national Cooperative Extension IPM survey showed that many farmers using IPM methods have lowered their pest control costs and increased net returns without sacrificing crop yield or quality (Rajotte et al., 1986). The survey also found that in some states, farmers using IPM considered environmental and public health benefits to be more important than economic benefits. A study of California tomato growers found that economic factors were most important to growers who had adopted IPM sampling techniques; other important influences on adoption were sources of information, previous experience with IPM, and the perceived complexity of IPM (Grieshop et al., 1988).

Despite the benefits of IPM perceived by some farmers, adoption has not been universal. To encourage adoption, several states have considered the marketing potential for fruits and vegetables certified and labelled as "IPM-Grown" (e.g., Grant et al., 1990). A certification program is being developed by the Massachusetts Department of Food and Agriculture. Before this program was initiated, we surveyed New England extension clientele (consumers), farmers, and representatives of the New England food industry to learn their perceptions and attitudes toward "IPM-Grown" certification and labelling. The results will provide information for New England food producers to decide whether an IPM certification program is advantageous for their marketing systems. The survey results also will help Cooperative Extension to improve new and existing IPM, food and nutrition educational programs.

Methods

The sample population was based on the following components of the food system: consumers, farmers (farmstand owners), wholesalers, processors and retailers. A total of 750 surveys were mailed.

We based the proportion of respondents selected from each component of the food system on the following geographical, statistical and logistical considerations. Con-

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sumers' names were selected randomly from Cooperative Extension mailing lists from one urban county and one rural county (except in Rhode Island) in each of the six New England states. Counties were selected randomly, with 40 names selected from each county. Thus, we selected 480 consumers. The remaining 270 questionnaires were allocated among food industry components in proportion to their size, with three farmers or retailers equivalent to one wholesaler or processor. This ratio reflects our perception of the relative importance of these components in marketing IPM-labelled produce. Wholesalers (36) and processors (36) were selected in proportion to the number of businesses in each state. The remaining questionnaires (102) were mailed to farmstand owners.

Farmstand owners were selected because of their unique position as producers and retailers. This position makes them potential beneficiaries of programs that identify IPM-grown produce.

Farmstand owners (102) and wholesalers of produce (36) were randomly selected from lists provided by the Department of Agriculture in each state. All retailers (96 produce managers of chain stores) listed in the current Grocery Industry Directory of New England and Albany were included, and 36 food processors who deal with produce were randomly selected from this directory.

Questionnaires were mailed according to guidelines described by Dillman (1978). We sent postcards to all prospective respondents one week after the first mailing. Follow-up letters and surveys were sent to all those who had not responded three weeks after the first mailing.

The survey instrument was tailored for each of the above respondent categories. Questions regarding self-reported knowledge of IPM, perceptions of current pesticide use and IPM, and attitudes toward IPM certification and labelling were common to all surveys, as shown in Figure 1. Responses to these questions are the focus of this report.

Survey participants were first asked whether they had ever heard of IPM and how much they knew about it (Questions 1 and 2, Fig. 1). We then gave six statements regarding perceptions of current pesticide use, with the following five response cate-

1. Before you received this survey, had you heard of INTEGRATED PEST MANAGEMENT or IPM?
   1. Yes
   2. No
2. How much do you know about INTEGRATED PEST MANAGEMENT or IPM?
   1. Nothing
   2. A little
   3. A moderate amount
   4. An extensive amount
3. There are no good reasons to use pesticides to grow food. **SA A U D SD**
4. Pesticides in food are responsible for a high incidence of human cancer. **SA A U D SD**
5. The government adequately regulates the use of pesticides. **SA A U D SD**
6. Farmers use pesticides safely. **SA A U D SD**
7. Most pesticides are safe if used according to government regulations. **SA A U D SD**
8. Foods with very small amounts of pesticide in them are safe to eat. **SA A U D SD**
9. When farmers have determined that pest levels in a crop have reached levels that will cause significant crop loss, the use of pesticides is justified. **SA A U D SD**
10. Produce grown using integrated pest management is safer than non-IPM-grown food. **SA A U D SD**
11. Produce grown using integrated pest management is as safe as organically-grown food. **SA A U D SD**
12. The use of integrated pest management helps the environment. **SA A U D SD**
13. Do you support the idea of "IPM-Grown" labelling?
    1. Yes
    2. No
14. If you do **NOT** support the idea of "IPM-Grown" labelling, why not?
    _____
    _____
15. Would you buy IPM-labelled produce over nonlabelled produce if it cost the same?
    1. Yes
    2. No
16. Would you buy IPM-labelled produce over nonlabelled produce if it cost somewhat more?
    1. Yes
    2. No
17. If Yes, how much more would you be willing to pay for IPM-labelled produce?
    1. 5%
    2. 10%
    3. 15%
    4. 20%
    5. Other (specify)_____
18. If an IPM label program were started in your state, who should certify crops as meeting IPM standards?
    1. State Department of Agriculture
    2. Private Organization
    3. A Farmers' Association
    4. Other (specify) _____
    5. Undecided

Figure 1. Questions and statements common to all questionnaires.

gories: "Strongly Agree", "Agree", "Undecided", "Disagree", and "Strongly Disagree" (Questions 3-8, Fig. 1). A variable was created to summarize responses to the six statements. Responses were first scored on a scale from 1 to 5; 1 indicates an attitude that current pesticide use is necessary, safe, adequately regulated by the government, and a minimal health risk; 3 corresponds to "Undecided"; 5 indicates an attitude that current pesticide use is unnecessary, unsafe, inadequately regulated by the government, and a health risk. A mean response score for the six statements was computed for each respondent, with respondents then grouped into three categories for comparative analysis. The response score range (1-5) was divided into thirds for this purpose: 1 to 2.33; 2.34 to 3.66; and 3.67 to 5.

Respondents were then presented with the following description of IPM:

> INTEGRATED PEST MANAGEMENT or IPM is an approach to crop protection that uses information about weather, pest numbers and growing conditions to make pest control decisions. Farmers in IPM programs generally use non-chemical and chemical methods to control pests. Non-chemical methods include beneficial insects, resistant crop varieties, crop rotation, cultivation, and pruning. Pesticides are used only when pest numbers reach levels that will cause significant crop damage. Pesticides are selected and applied in a way that causes the least disruption to the environment.
>
> In a number of crops, IPM programs have been effective in reducing pesticide use. In Massachusetts, IPM programs for fruit and vegetable crops have reduced pesticide use by 40 to 60 percent.

Following this definition, four statements were given to elicit respondents' perceptions of IPM (Questions 9-12, Fig. 1). Survey participants were then presented with this paragraph:

> A number of states in the Northeast are exploring the possibility of offering programs to qualified farmers to have their crops certified as "IPM-Grown." Growers who meet specific standards would be able to advertise or label their food as meeting these standards. In this section we ask your attitudes toward an "IPM-Grown" label.

We asked five questions to learn about respondents' support or lack of support for IPM certification and labelling (Questions 13-17, Fig. 1). Lastly, survey participants were asked who they thought should certify crops as meeting IPM standards if an IPM certification program were started in their state (Question 18, Fig. 1).

We analyzed the data using SAS (1985). Descriptive statistics and the χ^2 test for homogeneity were used to determine differences among categories in their self-reported knowledge, perceptions, and attitudes. We collapsed categories of respondents where necessary to create groups large enough for a statistically valid test.

Results

The overall response rate was 73% (n=549). Consumers (n=355, 74% response) represented the largest proportion of respondents, followed by farmstand owners (n=88, 86% response), retailers (n=59, 61% response), wholesalers (n=30, 83% response), and food processors (n=17, 47% response).

There were significant differences in responses among the categories of respondents. Farmstand owners differed consistently from other respondents regarding nearly all the questions asked in common. Differences among the categories in self-reported knowledge, perceptions, and attitudes were statistically significant (χ^2 test for homogeneity, $p<0.001$, except concerning the safety of organic versus IPM-produced food, for which $p=0.018$).

Most respondents (61%) reported that they had not heard of IPM before receiving the survey (Table 1), and 73% reported that they knew little to nothing about IPM. Farmstand owners were much more likely than other respondents to have heard of IPM (94%) and to know a moderate to extensive amount about it (83%). In contrast, no more than 25% of the consumers, retailers, wholesalers, or food processors reported having heard of it or knowing much about it.

Among all respondent categories, slightly more respondents (44%) considered current pesticide use to be necessary, safe, adequately regulated by the government, and a minimal health risk, than did not (40%) (Table 2). However, only 32% of the consumers had a positive opinion of current pesticide use. Farmstand owners and retailers were more likely than other respondents to consider current pesticide use safe.

The majority of respondents in all categories, except farmstand owners, agreed or strongly agreed that IPM-grown produce is safer than non-IPM-grown food (Table 3). Farmstand owners were much more likely than other respondents to agree or strongly agree that IPM-grown produce is as safe as organically grown food, while many respondents in all categories were undecided.

After reading the description of IPM, 65% of the respondents agreed or strongly agreed with the statement, "When farmers have determined that pest levels in a crop have reached levels that will cause significant crop loss, the use of pesticides is justified" (Table 3). Farmstand owners were more likely (97%) to consider pesticide use to be justifiable under IPM guidelines than were other respondents.

The majority of respondents (63%) agreed or strongly agreed with the statement, "Produce grown using IPM is safer than non-IPM-grown food." Response to the statement, "Produce grown using IPM is as safe as organically grown food," was almost equally distributed in the categories of agree/strongly agree (33%), disagree/strongly disagree (29%), and undecided (34%).

Most respondents (78%) agreed or strongly agreed with the statement, "The use of IPM helps the environment," with at least 60% of the respondents in each category agreeing. Because so few respondents disagreed, the χ^2 test was inappropriate.

After reading the paragraph about IPM certification and labelling, the majority of respondents in all categories supported the idea of "IPM-Grown" labelling (Table 4). Of the respondents who did not support or were undecided about the idea, 10% thought that a "IPM-Grown" label would be confusing to consumers. Another 10% mentioned that public education about

Table 1. Responses (%) to questions regarding knowledge of IPM.

	Consumers n=332	Farmstand Owners n=85	Food Processors n=16	Retailers n=52	Wholesalers n=30
"Before you received this survey, had you heard of Integrated Pest Management or IPM?"[1]					
Yes	24	94	19	25	10
No	76	6	81	75	90
"How much do you know about Integrated Pest Management or IPM?"[2]					
Nothing to a little	90	17	100	88	97
Moderate to extensive amount	10	83	0	12	3

[1] n=515, χ^2=162.2, p<0.001. In all tables, χ^2 tests whether responses were significantly different among categories of respondents.
[2] n=515, χ^2=230.1, p<0.001.

Table 2. Comparison of respondents' perceptions of current pesticide use based on a variable created to summarize responses to six questions.

Mean Score	Percent Response[1]				
	Consumers n=320	Farmstand Owners n=85	Food Processors n=15	Retailers n=56	Wholesalers n=30
1 - 2.33 (Pesticide use is safe and necessary)	32	88	53	70	60
2.34 - 3.66 (undecided)	9	1	13	9	13
3.67 - 5 (Pesticide use is unsafe and unnecessary)	59	11	33	21	27

[1] n=507, χ^2=105, p<0.001.

IPM is needed before the label is introduced. Other reasons for lack of support (or indecision) most frequently mentioned were: IPM certification standards would be too difficult to enforce; IPM certification would create a negative public perception of conventional agricultural practices and the safety of our food supply; and an IPM certification program and label would be too expensive to implement.

Most respondents (75%) said they would buy IPM-labelled produce over non-labelled produce if it cost the same (Table 4). Many (40%) said that they would buy it if it cost somewhat more than non-labelled produce; 35% of all respondents were willing to pay at least 5% more for IPM-labelled produce. Consumers were more willing than respondents in other categories to buy IPM-labelled produce over non-labelled produce if it cost the same or somewhat more. Twenty-four percent of the consumers were willing to pay up to 5% more for IPM-labelled produce, and 25% were willing to pay 10-20% more. This question has different implications for the different categories. The pricing decisions of retailers, wholesalers and processors depend directly on consumer preferences. However, consumer choice does not depend on the preferences of the other categories.

The different categories responded similarly regarding who should certify crops as meeting IPM standards. In response to the question, "If an IPM program were started in your state, who should certify crops as meeting IPM standards?", 53% of the respondents selected the State Department of Agriculture, and 27% selected either a private organization, a farmers' association, or some combination of the possible selections.

Discussion

This study shows that general knowledge of IPM among extension clientele (consumers) and food industry representatives is very low in New England, while farmstand owners are generally knowledgeable about IPM. Burgess et al. (1989) found that 73% of New York consumers participating in an IPM marketing survey had never heard of IPM. In their report on the feasibility of a New York IPM-grower recognition program, Grant et al. (1990) acknowledged the need for public education about agricultural practices in general, and IPM in particular.

Table 3. Comparison of respondents with respect to their perceptions of integrated pest management.

Statement	Response[1]	Percent Response				
		Consumers	Farmstand Owners	Food Processors	Retailers	Wholesalers
Pesticide use is justifiable under IPM guidelines[3]		(342)[2]	(86)	(15)	(54)	(29)
	Agree	60	97	60	76	72
	Undecided	21	1	40	15	17
	Disagree	19	2	0	9	10
IPM-grown produce is safer than non-IPM grown food[4]		(336)	(87)	(15)	(55)	(30)
	Agree	74	46	67	62	53
	Undecided	19	30	27	27	37
	Disagree	7	24	7	11	10
IPM-grown produce is as safe as organically-grown food[5]		(336)	(87)	(15)	(54)	(30)
	Agree	30	52	40	37	30
	Undecided	37	28	40	33	47
	Disagree	34	21	20	30	23

[1] "Agree" denotes actual response of "agree" or "strongly agree"; "Disagree" denotes actual response of "disagree" or "strongly disagree."
[2] Number of responses.
[3] n=526, χ^2= 50.6, p<0.001.
[4] n=523, χ^2= 34.9, p<0.001.
[5] n=522, χ^2= 18.4, p=0.018.

Table 4. Comparison of respondent support (%) for integrated pest management certified produce.

		Consumers	Farmstand Owners	Food Processors	Retailers	Wholesalers
Do you support the idea of "IPM-Grown" labelling?[3]		(338)[1]	(88)	(16)	(87)[2]	
	Yes	84	57	69	67	
	Undecided	11	23	31	20	
	No	5	21	0	14	
Would you buy IPM-labelled produce over non-labelled produce if it cost the same?[4]		(340)	(87)	(15)	(86)	
	Yes	86	66	73	61	
	Undecided	9	15	20	30	
	No	5	20	7	9	
Would you buy IPM-labelled produce over non-labelled produce if it cost somewhat more?[5]		(338)	(88)	(15)	(56)	(30)
	Yes	49	30	33	25	30
	Undecided	37	25	47	32	37
	No	15	46	20	43	33

[1] Number of responses.
[2] Responses for retailers and wholesalers combined for first two questions.
[3] n=529, χ^2= 40.7, p<0.001.
[4] n=528, χ^2= 48.8, p<0.001.
[5] n=527, χ^2= 55.0, p<0.001.

This study also shows that New England consumer clientele have little confidence in the current use of pesticides. Surveys by Ott et al. (1991), Sachs et al. (1987), Warren (1990), and the Food Marketing Institute (1990) also found that many consumers consider current pesticide use to be a potentially serious health hazard. Retailers, wholesalers, and food processors participating in this survey also had relatively low confidence in current pesticide use.

Most respondents, except farmstand owners, felt that IPM-grown produce is safer than non-IPM-grown produce, but not as safe as organically-grown produce. Organic produce is generally defined as grown without synthetic fertilizers and pesticides. An Institute of Food Technologists' report (Newsome et al., 1990) found that many scientists do not consider organic produce and, by extrapolation, IPM-grown produce, to be any safer to eat than conventional produce. Prokopy et al. (1980) acknowledge that the advantages of using IPM are lower pest control costs and fewer detrimental effects on the agricultural environment. Kovach et al. (1992) present an analysis showing that, in some cases, IPM has less effect on the environment than the pest control practices of either organic or conventional agriculture. Most respondents agreed that using IPM helps to protect the environment.

Although most respondents did support the idea of "IPM-Grown" labelling, some mentioned potential barriers to this type of label, including: ability to enforce IPM certification standards; cost of enforcement and labelling passed on to consumers; and confusion among consumers. Some of these barriers currently inhibit the marketing of organic produce. A survey of produce merchandisers for Virginia chain stores found several reasons that penetration of organic produce into the mainstream market has been delayed: the influence of upper management in large chain stores; lack of profitability resulting from irregular produce supply and sales; consumer education problems; packaging problems; and lack of national standards (Beamer and Preston, 1991). Barriers to the success of organic produce according to California produce managers include unavailability and low volume, poor quality and lack of consistent standards (Jolley and Norris, 1991). Some of these barriers may be important in the marketing of IPM-grown produce.

Our finding that 40% of consumers are willing to pay more for IPM-labelled produce is similar to that of Burgess et al. (1989), who found that 55% of New York consumers surveyed were willing to pay up to 25% more for IPM-grown produce. The higher cost of organically grown produce has limited its success, but 30% of the California consumers surveyed by Jolly et al. (1989) said they were buying it more frequently. Ott et al. (1991) acknowledges a discrepancy among Georgia consumers; although 57% thought that testing and certification of produce (as pesticide-free) was very important, fewer than 10% were willing to pay more than 10% extra for it. Given the limited knowledge of IPM shown by this survey, it would be interesting to learn whether New England consumers who know more about IPM are as willing to pay more for IPM-labelled produce. Farmstand owners and food industry representatives in this study were less willing to pay the same or somewhat more for IPM-labelled produce, which may be due to concerns about economic loss. The results, however, may be used by Cooperative Extension specialists to educate farmers and food industry representatives who are hesitant to introduce IPM-labelled produce.

Education of consumers and food industry personnel can play an important role in determining the success of a proposed IPM certification program in Massachusetts. To increase confidence in our food supply, consumers and food industry personnel need to be informed about IPM and other agricultural practices and their consequences. Further research is necessary to learn how best to provide information about the demonstrated and potential advantages of IPM without reducing confidence in the current food system.

There is a strong difference between farmers (as represented by farmstand owners) and non-farmers in their perceptions and attitudes concerning how agriculture affects the environment. These differences present a unique challenge to a marketing program that emphasizes environmental stewardship. An IPM label may be useful in encouraging farmers to adopt IPM methods and to give consumers more choices in the marketplace, but further study of the potential market barriers is needed.

Although this survey shows support for IPM certification and labelling in New England, the results are not necessarily generalizable to all New England consumers, farmers, or food industry representatives. Populations represented in this survey were New England extension clientele (consumers), farmstand owners who were members of statewide farmstand associations in New England, produce managers of supermarket chain stores that are members of the New England Wholesale Food Distributors' Association (NEWDFA), representatives of food processing companies that deal with produce and are members of NEWDFA, and New England wholesalers who deal with produce.

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Agricultural Research Alternatives, by William Lockeretz and Molly D. Anderson, 248 pages, hardcover, is available for $30 from University of Nebraska Press, P.O. Box 880520, Lincoln, NE 68588-0520.

Growing into the 21st Century, conference proceedings, are $15 from National Association of Conservation Districts Service Center, 408 East Main St., PO Box 855, League City, TX 77574; 1-800-825-5547.

Production Practices and Sample Costs for a Diversified Organic Vegetable Operation in the Central Coast is available from Department of Agricultural Economics, University of California, Davis, CA 95616; (916)752-9376,

The Thompson Farm On-Farm Research, 1992 Edition, is available from Dick and Sharon Thompson, 2035 190th St., Boone, IA 50036-7423; (515)432-1560.

Ohio Organic Suppliers Directory is $15 from Ohio Ecological Food and Farm Association, PO Box 02247, Columbus, OH 43202.

1993-1994 Products and Services Directory, $16.50, and *Preserving Our Environment—The Race is On*, $45, are available from International Erosion Control Association, PO Box 774904, Steamboat Springs, CO 80477; (303)879-3010.

Tradeoffs Between Water Quality and Profitability in Iowa Agriculture is available from Cheryl K. Contant, University of Iowa, Public Policy Center, 227 South Quadrangle, Iowa City, IA 52242-1192; (319)335-6800.

Audio tapes from nationwide conferences and about timely topics are available from agAccess, 603 Fourth St., Davis, CA 95616; (916)756-7177.

Sustainable Agriculture and the Environment in the Humid Tropics, by the National Research Council, is available for $49.95 plus $4 shipping from the National Academy Press, 2101 Constitution Ave., NW, Box 285, Washington, DC 20055; 1-800-624-6242.

Sustainable agriculture materials from the USDA's Extension Service include fact sheets on attitudes of U.S. farmers, the SARE program, and state accomplishments under the sustainable agriculture initiative; plus several feature stories about sustainable farmers; contact Judith A. Bowers, Communication, Information, and Technology, USDA—Extension Service, Washington, D.C. 20250-0900.

Updated List of Information Products and Publications is available from Alternative Farming Systems Information Center, National Agricultural Library, 10301 Baltimore Blvd., Beltsville, MD 20750-2351; (301)504-6559.

Organic Soil Amendments and Fertilizers, a 36-page booklet, is $5 from ANR Publications, University of California, 6701 San Pablo Ave., Oakland, CA 94608-1239; (510)642-2431.

Pennsylvania Sustainable Agriculture Project—1992, published by American Farmland Trust and Pennsylvania Association for Sustainable Agriculture, is available for $5 from AFT, Center for Agriculture in the Environment, P.O. Box 987, DeKalb, IL 60115; (815)753-9347.

Sustainable Agriculture Directory of Experts, 300 pages, is $14.95 from Sustainable Agriculture Publications, Hills Building, Room 12, University of Vermont, Burlington, VT 05405.

Natural Enemies of Vegetable Insect Pests, a 64-page manual with 85 color prints, is $22.50 from the Cornell University Resource Center, 8 BTP, Ithaca, N.Y. 14850; (607)255-2080.

Cereal and wool production in the Esperance Sandplain area of Western Australia: The need for a systems approach for sustainable agriculture

Murray Fulton

Abstract. *The problems facing farmers in the Esperance Sandplain region of Western Australia—salinity, herbicide resistance, wind erosion, and plant disease—are highly interrelated. Unless the biological, economic and social aspects of the problems are examined in an integrated way, no sustainable system will be found. Similarly, agricultural teaching and research must become much more integrated if they are to address agricultural and environmental problems satisfactorily. This will require changes in the structure of university and research institutions and in the rewards for research and teaching.*

Key words: sustainable development, systems analysis, salinity

Sustainable development is becoming an increasingly important aspect of political and economic life (Batie, 1989; Pearce et al., 1989). Several concepts are inherent in sustainable development, including a concern about equity (both intra- and intergenerational), a focus on the limits of the biosphere in supplying energy and absorbing pollution, and the need for integrated biological, economic and social analyses.

This paper addresses the last of these concepts. In the next section I present a definition of sustainable development and link this definition to the notion of a system. That section also discusses how focusing on only one or two components of the system can lead to a suboptimal outcome for the entire system. I then examine agricultural practices in the Esperance region of Western Australia to illustrate a system that is not sustainable. I conclude that unless the problems are examined in an integrated way, no sustainable system will be found.

By analogy, I then argue that agricultural teaching and research must become much more integrated if they are to address current and future agricultural and environmental problems satisfactorily. Instead of viewing agricultural problems as separate and independent, a systems approach must be developed that takes an integrated view of agriculture. This will require changes in the structure of university and research institutions and in the way research and teaching are rewarded.

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Sustainable Development and a Systems Approach

Sustainable development has many definitions (see Pearce et al., 1989, Appendix, for a comprehensive list). For this paper, Norgaard's definition (1988, p. 607) is perhaps the most suitable. He defines sustainable development with five increasingly comprehensive definitions, beginning with the following:

> First, we can start at the local level and simply ask whether a region's agricultural and industrial practices can continue indefinitely. Will they destroy the local resource base and environment or, just as bad, the local people and their cultural system? Or will the resource base, environment, technologies and culture evolve over time in a mutually reinforcing manner? This first definition ignores whether there might be subsidies to the region—whether material and energy inputs or social inputs such as provision of new knowledge, technologies and institutional services are being supplied from outside the region.

In the four remaining definitions, Norgaard asks the following: whether the region in question is dependent on outside sources of non-renewable resources and renewable resources managed unsustainably; whether it is culturally sustainable in that it contributes as much to knowledge and institutions of other regions as those regions contribute to it; whether it is contributing to global climate change, so that other regions are being forced to respond; and finally, whether all the regions in combination are culturally stable in the sense

of evolving along mutually compatible paths.

An important part of this view of sustainable development is that the economic, social and biological components of a system must be treated as interrelated. In particular, Norgaard (1988, p. 614) argues that sustainable development rejects the view prominent in modern society that systems can be understood solely by understanding each component.

Agriculture is a good example of a system with biological, economic and social elements. However, these components generally are not considered together. The academic study of agriculture is highly specialized, with each discipline separated from the others. Economists rarely talk to soil or plant scientists, and vice versa. Even within a discipline, research is highly specific. Although work is done on every component and sub-component of the system, little work is done that maps out the interactions among the components.

What is the effect of examining only one or two components of a much larger system? A partial answer can be obtained from economic theory. Economics in effect is the modeling of a system that is held together by economic and physical relationships. For example, the application of fertilizer affects crop yields, soil nutrient levels, and groundwater contamination, among others, through a series of physical relations. It also affects economic variables such as farm income and the income of input supply firms. The amount of fertilizer used is determined largely by the behavior of farmers and input supply firms as they attempt to satisfy economic objectives.

A question addressed by economic theory is the optimization of such a system according to economic, social and environmental objectives that are deemed important. Economic theory tells us that optimization requires an analysis that considers all the components and their interactions. The components of a system can correctly be analyzed in isolation only under two conditions: when there are no effective linkages between the components under study and the other components of the system; or when all other parts of the system are at their optimum.

The first of these criteria is straightforward. If the goal is to maximize farm income, all linkages between the factors affecting farm income must be considered. Failure to examine the effects that cropping practices of today will have on weed problems of tomorrow, for instance, will lead to less than maximum income. Similarly, if the goal is to obtain the highest economic value consistent with environmental preservation, the effects of fertilizer use on groundwater contamination must be considered.

Interestingly, there are circumstances when components of the system can be ignored, even if they are interrelated. This point is addressed with the second criterion. According to the economy theory of the second best, a system's components can be analyzed separately only if all other components are already in their optimal state (Henderson and Quandt, 1971). For example, in the problem of maximizing economic value subject to environmental preservation, if groundwater contamination can be held at its desired level it is not necessary to consider the effect of fertilizer on this component.

Since this second consideration is almost never met, the implications for modeling agricultural and natural resource problems are clear; if there are linkages between the components, it is necessary to consider all the components, not just a subset. Failure to do so will lead to a suboptimal solution for the system.

In the next section I present an example of an agricultural system that is not sustainable. The following discussion uses the first level of Norgaard's definition of sustainable development (see above). To use that definition we must specify the region being analyzed. In the example below, this region is defined naturally by the physical setting.

The Physical Setting

The Esperance area is 300 km east-west by 100 km north-south, and lies along the southern coast of Western Australia. The southern boundary is centered on the port town of Esperance. The land slopes southward in a level to undulating plain.

The southern half of the district is known as the Esperance Sandplain. Its predominant soil is fine sand overlying a sandy clay loam (Stoneman et al., 1990). The sand varies in depth from 30 to 100 cm, with pockets up to 10 m. North of a line about 45 to 50 km from the coast lies the "mallee" area, so-called because the soil is heavier (higher in clay) and can carry taller trees (the mallee). The soil in this area is typically a shallow fine sand over sandy clay and sandy loam (Stoneman et al., 1990). In both the sandplain and the mallee areas, soil types vary dramatically. One farm may have five or six different soil types, many of them within the same paddock.

Annual average rainfall along the coast is about 650 mm, decreasing to about 400 mm at the southern edge of the mallee area. Rainfall is highly variable from year to year. As is typical in a Mediterranean climate, rainfall occurs mostly during the winter (May to October), which also is the growing season.

The Current Farming System

Agricultural production is recent in the Esperance area. The first land was cleared about 35 years ago, with some parts cleared only 10 years ago (Hearn, 1991). Initially, the land was cleared using bulldozers and chains, with almost all the native cover of trees and bush uprooted and burned. Although the clearing technique has remained the same, recently there has been more discrimination in what is cleared. This is partly due to legislation specifying that land with high potential for degradation may not be cleared.

The traditional agricultural production system in the area is pasture with occasional cropping. Recently, farmers have shifted toward systems based on soil type and landform. This has led to very specific rotations. For example, continuous pasture is common on shallow duplex soils (15 cm of sand over clay), while a cereal/pasture rotation is common on loamy fine sand and fine sand (Stoneman et al., 1990). The cereal crops in this rotation are mainly wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*), while the pasture is annual clover (most commonly *Trifolium subterraneum*). On transitional alkaline soils, medicago species (medics) replace clover. Sheep are grazed on the land during the pasture phase. The cereal/pasture rotation has provided diversification, a source of nitrogen for cereal production, and a method of breaking weed and disease infestations.

In the past 10 to 15 years, lupins (*Lupinus* spp.) have been added as a part of a pasture rotation, such as cereal/lupins/cereal/pasture, or as part of a continuous

cropping system (cereal/lupins). The latter has been particularly effective on sands of medium depth. Lupins are both a source of nitrogen for cereal production and a cash crop (although some farmers keep them as a supplementary feed during the summer). They also are a source of stubble for sheep; however, there is a problem with lupinosis, a disease that sheep contract after eating fungal-infected lupin stubble. Internal soil drainage determines whether lupins can be grown successfully. Typically, a sandy soil to a depth of more than 50 cm is required, with at least one meter preferred.

Canola (*Brassica napus*) was tried in the early 1970s, but was discontinued because of black-leg disease. In the past few years, canola has been reexamined as a potential crop, because varieties resistant to black-leg have been developed. Besides being a cash crop, canola can be used in a rotation to break disease cycles or to remove grassy weeds (barley grass [*Hordeum leporinum*], brome grass [*Bromus hordeaceus* and *B. diandrius*], silver grass [*Vulpia* spp.], and ryegrass [*Lolium rigidum*]) by using grass-selective herbicides. Alfalfa (*Medicago sativa*) has been tried as a perennial pasture. However, it is easily overgrazed and is subject to insect attack (Hearn, 1991).

Grassy weeds are a major problem, lowering yields of barley and wheat. Also, they are a poor feed for sheep, especially barley grass. Until about 10 years ago, weeds were controlled primarily by cultivation and by heavy grazing of the grasses in the spring. Control was also achieved by growing and cutting hay. Recently, however, chemical sprays have become widely used.

Pasture being cropped in the following year is usually sprayed in November with a knockdown herbicide such as glyphosate to prevent seed set on the grassy weeds. The timing is important, since farmers wish to have much of the seed set on clover before spraying. Spraying at this time is only moderately successful in removing grasses that harbor take-all root disease (see below). Some farmers do use grass-selective herbicides earlier in the season, but this appears to contribute to greater erosion during the summer and to the development of herbicide resistant grass (see below).

For wheat and barley crops, a second spraying with chlorsulfuron or a knockdown herbicide (glyphosate, or diquat and paraquat) is done before seeding in May. In wheat, a third spraying for broadleaf weeds is often done after the crop is up. In barley, diclofop may be used post-emergence if required. For lupins, a knockdown herbicide is used in the spring before seeding, followed by a post-emergence grass herbicide, such as fluazifop or haloxyfop.

A rapidly emerging problem is the build up of resistance to herbicides in ryegrass. Three major groups of chemicals are used to control ryegrass: "Fops," e.g., fluazifop, quizalofop, and diclofop; "Dims," e.g., tralkoxydim and sethoxydim; and sulphonylureas, e.g., chlorsulfuron and triasulfuron. Resistance can be evident after six or seven applications of a particular herbicide group; in 10 to 15 years, almost the entire population of ryegrass can be resistant. Resistance to a particular herbicide seems to occur primarily from use of herbicides in the same group, although some cross-group resistance has been reported (Western Australian Dept. of Agriculture, 1991).

A major disease in the area is take-all, caused by a root fungus that grows on cereal crops. An effective way of controlling this disease is to remove cereals from a paddock for one or two years.

An Unsustainable System

Several problems have emerged in the Esperance farming system. In the past eight to ten years, soils have begun to become saline in low areas. The problem occurs because the water table is rising and the groundwater is naturally saline (up to two or three times higher than sea water, but often less). The rising water table is a direct result of agricultural practices (Hearn, 1991; McFarlane and Ryder, 1990; Western Australian Dept. of Agriculture, 1988). Water uptake by the annual crops—cereals, clover, lupins and canola—is much less than that of the native vegetation. As a result, the water table is slowly rising even in low rainfall areas (450 mm and less). The problem is that about two-thirds of the rainfall occurs during the growing season; any water above the crop's needs goes to the water table. Also, summer rainfall is not used well by winter annuals.

A second problem is wind erosion, mainly during the summer. Ironically, it results from the concentrated nature of the rainfall. Most vulnerable are the extremely sandy soils and those that have been in pasture during the winter, particularly if the pasture is nearly all clover. Removing the grass leaves the soil much more exposed to wind erosion in the summer and reduces water use. However, removing the grass also has several benefits; it improves the pastures, potentially allows an improved crop the following year, and effectively controls take-all if the grass is removed for one or two years.

A third problem is that ryegrass is resistant to selective herbicides (Western Australian Dept. of Agriculture, 1991). This problem can disrupt the continuous cropping cereal/lupin rotation and significantly reduce the yields of both pasture and crops.

A fourth problem is water repellent soils (McFarlane and Ryder, 1990). This problem is worse where legumes make up a larger proportion of the rotation; it is less severe where wheat is grown continuously. A reason for this is that lupins are grown only on the deeper sands, which take longer to wet from underneath. Water repellent soils have the obvious effect of reducing water availability to plants, but they also may cause the water to move more quickly through the soil profile by concentrating it in permeable areas, thereby raising the water table. Finally, water erosion also is a problem, particularly on hilly land and during periods of high rainfall or low crop cover.

Several strategies to address these problems have been tried, generally in combination. A common way of dealing with salinity is to use more water in low-lying areas by planting trees and bush, including salt-resistant varieties. This is costly, because the areas must be fenced to keep sheep from grazing the plants. Fencing also prevents the overgrazing of surface cover and helps to define a management unit.

A second method of dealing with both the water table problem and erosion is to control surface runoff by a combination of methods. These include: "W" drains (two side-by-side trenches with the soil thrown up into the middle and to the outside, forming a cross-section like a W); grade banks (banks that zig-zag along the side of a hill to direct water slowly around the hill rather than straight down); scraper drains (drains dug with a scraper, about 2 m wide and 2 m deep, that move large volumes of water); and grassed waterways. Besides being extremely costly, these efforts really only export the problem: the phrase "we'll send it

down to Esperance [sea]" is common. When farmers discharge water, legally it must be lower in salt than the stream or river that receives it.

Fencing according to soil type is a third solution that is being tried. By changing paddock size and shape to conform to soil types, farmers are attempting to match crops to particular topographical and soil characteristics. For example, they plant perennial pasture where the water table is high, and are continuously cropping areas where wind erosion is a problem.

Planting windbreaks every 150 to 200 m also is being examined as a way to deal with wind erosion and the rising water table. The trees protect the crop from the wind. Experiments done on one farm gave the following results: "Lupin yields between the four and then five year old pine windbreaks, spaced 200 m apart, increased by 28% in one year and 30% in another. The net yield increase, after deducting the area taken up by the windbreaks, was 19% and 22% in the two years measured. These gains are for the entire paddock. Peak yield increases between the windbreaks were over 50%" (David Bicknell, Revegetation Development Officer, Western Australian Dept. of Agriculture, personal communication, 1992). Another effect of windbreaks is to draw down the water table. Observation wells located next to the windbreak on the farm mentioned above showed a much lower water table than wells drilled between the windbreaks. Also, the water table was falling where the trees were planted, although it was continuing to rise in another paddock with no trees.

The last mechanism for dealing with the rising water table is to plant fodder trees such as tagasaste (*Chamaecytisus proliferus*). Tagasaste is a leguminous tree shrub that can be eaten by sheep and cattle. It usually is planted in single rows, spaced about 5 m apart to accommodate machinery. Sheep and cattle will graze directly on the shrubs, or the tops can be cut for immediate feeding or for hay (Kleinig and Savage, 1988; Negus and Hawley, 1988). Salt bushes (shrubs that are resistant to salt) also are being grown on salt-contaminated land.

Fodder trees and salt bushes can lower the water table and combat wind erosion (Hearn, 1991). Besides using more water because of their greater biomass, they grow year round. This not only draws down the water table during the summer, but also provides feed during this period. Because of its greater biomass, tagasaste can support about three to five sheep per hectare per year, a considerable increase over the current average of just over one sheep per hectare per year.

Problems with crops such as tagasaste include the initial cost of establishing a stand and the cost of the machinery and labor for cutting. Although tagasaste generally recovers quickly after being cut or grazed, finding the appropriate grazing rate has been a problem. Reduced edibility also can be a problem, as was observed after a grasshopper infestation, for example.

Besides these physical and biological strategies, farmers have also adopted some social responses to their problems. A particularly important one is the Esperance Land Conservation Committee, a farmer-directed group covering the whole Esperance area. Within the area there are at least ten catchment, or Landcare, groups, each with about 10 to 15 members. Members of the catchment group meet regularly to discuss issues that affect the whole group and those that affect particular individuals, such as water drainage from one farm to another.

Toward a Sustainable System?

Is agriculture sustainable in the Esperance area? It always is risky to make predictions, but I believe that maintaining crop and livestock production in this area over the long run will require major changes. Even under Norgaard's least restrictive (first-level) definition of sustainability, current farming methods probably are not sustainable. Under his increasingly more stringent definitions, agriculture in the Esperance region almost certainly is not sustainable. The current production systems require significant importation of energy and materials, resources that are not managed sustainably in the rest of the world.

What would a sustainable system look like? Focusing on Norgaard's first-level definition, it must take a much more integrative approach to problems. As an example, the choice of crops and rotations affects both the rate of water buildup (or drawdown) and the types and amounts of weeds and disease. This in turn affects both short- and long-term costs and benefits. The cereal/pasture rotation has provided short- to medium-term benefits, but at the long-term cost of reduced productivity from salinity and water repellent soils. Attempts to achieve even greater short-term benefits by controlling grassy weeds and by switching to cereal/lupin rotations have had the beneficial effect of increasing water use. However, they also have had detrimental long-term effects on herbicide resistance and the spread of disease.

Controlling herbicide resistance in ryegrass or the build-up of take-all cannot be examined by themselves. Instead they must be examined along with the relative profitability and riskiness of different crop rotations and alternative uses of land. For example, using sheep to control ryegrass has obvious implications for rotations, as does planting barley to avoid the take-all problem (barley is more resistant to take-all than wheat). Also, ryegrass resistance is unlikely to be as serious in a regime dominated by tagasaste, or in a much longer pasture rotation that uses perennial crops.

An important added spatial dimension arises from the considerable variation in soil types, even within a paddock. As an example, how do practices on adjoining soil types interact, and what are the costs of shifting crops among different paddocks?

The water table problem also must be seen in the context of a larger, dynamic system. For example, reestablishing trees and shrubs in low-lying areas is likely to help solve disease and weed problems. Drainage may provide short-term benefits, but it also may not get at the fundamental problem, namely, that the standard crop rotations do not provide enough biomass to keep the water table constant. Other questions come to mind: What is the long-term profitability of establishing windbreaks? How does this compare with other management practices, such as growing fodder bushes or simply planting large areas to trees? What is the risk associated with these new practices?

The analysis must extend beyond the farm level. Sustainability is a collective concept; a production system must be sustainable over a wide area, not just on a single farm. This means that farmers must find ways to reduce the damage they cause beyond their own farms. The formation of

the Esperance Land Conservation Committee is a step in this direction.

A collective analysis must include how farmers can be induced to take control measures on their land even though the benefits go to other farmers. A dynamic, spatial view of the problem is important; farmers may be more likely to take appropriate actions if they know that these actions will influence other farmers who in turn make decisions that affect them.

Slope and soil type make most of the Esperance Sandplain a groundwater recharge area. Thus, control of the water table is going to depend on using more water in various ways, at many locations. These include perennial pastures, high production cropping systems, and better pasture management.

Also, it may be appropriate to plant regularly spaced trees and shrubs. Introducing more trees will increase water use, control wind erosion, protect crops and livestock, and conserve nature. It also could diversify farm enterprises by providing the basis for a wood chip industry. However, developing this new industry would require a great deal of cooperation and interaction among the area's farmers.

Besides the biological, physical, and economic aspects of sustainability, the social aspect also must be addressed. Farms in this region are large; there are 750 farms in the 1.9 million hectares comprising the Esperance advisory district of the Western Australian Department of Agriculture. Therefore, farm families are very isolated. Although children may attend primary school in a nearby town, students continuing with secondary education usually attend a boarding school in Esperance or Perth (750 km to the northwest). Although the experience of other parts of Australia suggests that farms can get much larger than in Esperance, the question of what is a sustainable community nevertheless is important.

Concluding Comments

A lesson from economic theory is that when interactions are present in a system, finding an optimal solution for only one part will make the whole system suboptimal. That is really the message of this paper; in a complex biological and physical environment like that of the Esperance area, developing sustainable agriculture requires a systems approach.

This view assumes that sustainable development is concerned with a system, not simply with some component of it. This seems obvious, but it has the important corollary that we need a method to view the whole system. I have assumed that economics plays this role. Consequently, what becomes important when analyzing the system are such things as profitability and riskiness of the various activities within the system.

The analysis can be extended. Arguing that riskiness is important is another way of saying that expected profitability is not all that matters to people both inside and outside the system. Other concerns that need to be considered include social interaction and community, and preservation of land and habitat.

At the conceptual level, movement toward sustainable agriculture means developing models of the biological and physical components of the system that emphasize the interactions among them. With these models, we can compare the economics—broadly defined as above—of various rotations and regimes.

Because the solution to this problem will be optimal for the system, not for one component, trade-offs will be necessary. For example, in the Esperance area it is unlikely that it will ever be desirable to control ryegrass completely or to eliminate all salinity. This may be hardest lesson to learn—that an optimal solution for the system is not obtained by optimizing the separate components.

This conclusion has particular importance not just for farming in the Esperance Sandplain, but for agricultural research and teaching. Agriculture has become increasingly specialized, and disciplines within agricultural faculties are becoming more separated from each other. The consequence is that academics and researchers are increasingly isolated from each other in proposing solutions to agricultural and environmental problems. By analogy with the Esperance Sandplain system, the effect of this academic isolation will be suboptimal solutions to the problems being examined.

Although some interdisciplinary work is being done, there are several barriers, including: the perceived weakness and illegitimacy of the social sciences within agricultural faculties; the greater amount of time required and the shortage of journals where it can be published; the lack of support structures that cut across disciplines; and conflicts over power and control of interdisciplinary projects (Heberlein, 1988).

Despite these problems, some attempts at system modeling are occurring. In Western Australia, MIDAS (A Bioeconomic Model of a Dryland Farming System), which was developed by the Western Australian Department of Agriculture, is a good example of how biological and economic elements can be considered together, and how farmers and researchers from a wide range of disciplines can work cooperatively (Kingwell and Pannell, 1987; Trenbath, 1989). More work must be done, however. For instance, the focus on maximizing long-term profits for individual farms must be replaced by a view of a catchment area that also incorporates social considerations (Gomboso et al., 1993).

To conclude, at least two changes are necessary (although not sufficient) to develop a sustainable agriculture. The first is philosophical, and involves a shift in thinking. Instead of viewing agriculture as a series of separate and independent problems, agriculture must be viewed as an integrated system. As McCloskey (1990) has stated, this shift in thinking will not be easy. The positivistic methodology that underlies agricultural economics, for instance, has led to the belief that problems can be handled separately by specialized researchers, but it also is the result of the extreme specialization among researchers.

The second change involves putting the systems approach into action by altering the structure of research and teaching. Although specialized efforts will need to be continued, they must be accompanied by methods that start with the interactions among the various components of the agricultural system. Agricultural colleges must be restructured, agricultural curricula must be changed, and reward systems for both teaching and research must be rethought.

These changes will be difficult. Heberlein (1988) argues that without changes in the administrative and institutional structures of universities and funding agencies, the costs of doing interdisciplinary research will remain prohibitively high. However, recognizing that institutional factors play a role in directing research is part of the answer, since a lesson from this

paper is that all the components of the system must be considered together to obtain a desirable solution.

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National Academy: Change Pesticide Procedures to Protect Children

The federal government should make substantial changes in the current pesticide regulatory system to give infants and children greater protection from possible adverse health effects of the pesticides in their diets, advocates a long-awaited report recently published by the National Academy of Sciences' National Research Council.

Pesticides in the Diets of Infants and Children recommends that the federal government "change some of its scientific and regulatory procedures for pesticides" and "adopt a new method of risk assessment to gauge more accurately what proportion of the population may be at risk." It also urges that tolerance levels regulating permissible levels of pesticides in food be based primarily on health considerations rather than on agricultural practices.

The 14-person committee that wrote the report found that both quantitative and occasionally qualitative differences in toxicity of pesticides between children and adults exist, and that infants and children differ both qualitatively and quantitatively from adults in their exposure to pesticide residues in foods.

"To properly characterize risk to infants and children from pesticide residues in the diet, information is required on (1) food consumption patterns of infants and children, (2) concentrations of pesticide residues in foods consumed by infants and children, and (3) toxic effects of pesticides, especially effects that may be unique to infants and children," the report said.

Among its recommendations, the report said it is "essential to develop toxicity testing procedures that specifically evaluate the vulnerability of infants and children." It also recommended refining estimates of total dietary exposure to consider multiple pesticides with common toxic effects. In estimating the risk that a pesticide might cause cancer, toxicologists now assume a lifetime of constant exposure. The committee recommended "the development of new methods that account for changes in exposure and susceptibility that occur as a person matures."

Pesticides in the Diets of Infants and Children, 373 pages, is $47.95 plus $4 shipping/handling, from National Academy Press, 2101 Constitution Ave., NW, Box 285, Washington, D.C. 20055; 1-800-624-6242 or (202)334-3313.

COMMENTARY

The question of good science

John E. Ikerd

Abstract. *Research serves different purposes for scientists and for farmers, and the two groups evaluate research results differently. Scientists are mainly concerned about the chance that they have reached an incorrect conclusion, while farmers are mainly concerned about the chance they will make an incorrect decision based on the results. Research conducted by farmers on their own farms can be more directly applicable to other farmers' conditions than experiment station research, and therefore can reduce the risk of an incorrect decision.*

Key words: on-farm research, experimental design, participatory research

Scientists and farmers naturally tend to view science differently. But they need to understand their differences if scientists are to provide information that is useful to farmers and if farmers are to be able to communicate their problems and information needs to scientists.

Farmers tend to be more interested in applied research results that provide knowledge of specific subjects or help them solve specific problems. However, the scientific community usually places a higher value on basic research that develops or improves theories or research techniques. Farmers need information that will help them reduce the risks of making wrong decisions in managing their farms. Scientists, on the other hand, may be more concerned about the risks of misinterpreting their research results and thus drawing wrong conclusions. Science that advances techniques and theories is not inherently better or worse than science that addresses the needs of farmers. However, differences in objectives and concerns can lead to communication difficulties between researchers and farmers. The sustainable agriculture community, in particular, needs to recognize and deal with these difficulties.

The dictionary defines science as "a state of knowing: knowledge as distinguished from ignorance or misunderstanding" (Merriam-Webster, 1983, p. 1051). Science is further defined to include knowledge about "general truths or the operation of general laws" and "system(s) or method(s) reconciling practical ends with scientific law." Science, then, may provide knowledge that is either basic or applied in nature. "The aim of science is to discover order; something which occurs with regularity, represents a relationship, or may be expressed in a law. . . . Science assumes order and its task is to discover it." (E.W. Allen, 1926, as quoted by Breimyer, 1991) Good science provides knowledge, understanding, or useful information concerning orderly, regularly occurring relationships.

Research is the process of scientific inquiry. Johnson (1988) contends that basic research should improve theories, techniques, and basic measurements, in particular those associated with academic disciplines such as chemistry, economics, or physics. Applied research should provide knowledge on specific subjects such as water quality, soil erosion, or food safety, or provide information on specific problems such as weed control, pesticide leaching, or nutrient management. Either type of research can be good science. However, science that addresses specific problems typically gets little weight when academic scientists are evaluated professionally. Tenure and promotions require publications in scientific journals that generally are refereed and read by other scientists, not by farmers or other information users.

Even the best science does not add perfect knowledge. All types of research involve risks of error. In basic research, errors can result in misdirected theories or inappropriate techniques. In applied research, errors can result in misleading information and, consequently, wrong decisions.

Farmers are primarily concerned with decision risks, the risks of wrong choices among alternatives. Farmers realize that they can never be certain regarding the future. Still, they want to know the chances that the outcome of one alternative will be better or worse than the outcome of another. Researchers, on the other hand, tend to be more concerned with conclusion risks. Their professional reputations hinge on the validity of their research conclusions.

Statistical inference allows researchers to assign a probability to the risk of a wrong conclusion, based on the number of treatments in an experiment, sample size, and statistical measures of variability. However, the risk of a wrong conclusion does not equal the risk of a wrong decision based on that conclusion. For example, researchers may report that one crop variety yields more than another at the 0.05 level of significance. This means there is only a 5% probability that the observed yield was higher because of chance or random error, rather than because the "winning" variety was superior. However, this probability

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applies only to the growing conditions under which the experiment was carried out, that is, the particular soil type, climate, pest pressures, management level, and so forth. The probability may be quite different than that the "winning" variety will perform better for a given farmer on a given field under next year's growing conditions. For example, the farmer's risk of realizing a lower yield from the "winning" variety might be 40%, rather than the 5% reported by the researcher.

Every experiment embodies two different types of risks; conclusion risks and decision risks, which can be expressed as different probabilities. The probability levels reported with research results reflect conclusion risks. The probability levels that are not reported, but are no less important, reflect decision risks.

Decision risks are related to conclusion risks only insofar as conclusions based on experiments or sample observations from the past give accurate insights into specific real world occurrences in the future. Scientific methods invariably involve abstraction and simplification of the real world to make its complexities comprehensible to the scientific mind (Breimyer, 1991). Scientists rarely, if ever, carry out experiments under conditions that accurately reflect actual growing conditions on commercial farming operations. To isolate relationships among the factors of primary interest, they hold other factors constant that are not constant under actual growing conditions. Even when conducting applied research, the scientist's primary role must be to discover or validate fundamental, recurring relationships rather than to find solutions to the specific problems of individual farmers. Research results would not be perfectly replicable even if experiments were designed to be realistic. The future is never identical to the past. In general, therefore, one should not expect the conclusion risks associated with completed experiments to reflect accurately the risks associated with future decisions.

Differences between conclusion risks and decision risks can be so great they make scientifically credible research results almost useless to individual farmers. This is true for all agricultural research, but is particularly true for research related to site-specific issues, such as those arising in sustainable agriculture. Obviously, differences between conclusion risks and decision risks can be reduced by making the research environment more like the environment in which management decisions ultimately will be made. Applied research, by definition, must be designed to provide useful information rather than to discover general truths. Adaptive research is designed to evaluate the extent to which previous research results can be replicated under realistic farming conditions. However, the role of an academic researcher is fundamentally different from the role of a farmer. While the gap between conclusion risks and decision risks may be narrowed by adaptive research, it is not eliminated.

One of the strongest cases for on-farm, participatory research is that it can minimize the gap between conclusion and decision risks. On-farm trials can have conclusion risks comparable to those of experiment station research (Rzewnicki et al., 1989). Experimental conclusion risks and farmers' decision risks may be quite similar when experiments are carried out by farmers, on their own farms, within their particular whole-farm systems.

A farmer at a recent national conference said that he considered top-down research to be 10 percent effective and farmer-to-farmer research to be 90 percent effective. This farmer participates in on-farm research projects. His assessment of relative risks was obviously subjective and relates to his particular situation. However, in his judgment, conclusion risks reported for top-down research were far different from actual risks associated with using those research results to make decisions on his farm. On the other hand, he considers results of on-farm participatory research, presumably carried out by himself and his neighbors, to be highly transferable among farms. He is assuming that these farms are more like each other than they are like experiment stations. Obviously, this assumption may not hold for all farms and experiment stations.

On-farm research programs such as those carried out by the Practical Farmers of Iowa and grassroots farm organizations in several other states have proven that on-farm research is feasible and that it can be practical and effective. Farmer-conducted field days, case studies, and informal contacts among farmers can provide them with valuable information about the whole-farm context within which research results were achieved. Such knowledge is necessary for farmers to make subjective assessments of the extent to which research results may or may not be replicable on their individual farms.

In summary, good science is the result of well-designed research that is carefully carried out to provide knowledge and information concerning orderly, regularly occurring relationships. However, the quality of science must be evaluated by its contribution to knowledge and information, not simply its experimental design or statistical conclusions. Good science may provide knowledge concerning fundamental laws or principles, or may simply provide information that is useful in solving problems or capitalizing on opportunities.

All scientific inquiry carries with it the risks of wrong conclusions and bad decisions. Scientists tend to classify research as good or bad science based on conclusion risks; they give much less attention to decision risks, even though the two may be quite different. Even a subjective assessment of decision risks may be much better than assuming that decision risks and conclusion risks are the same.

Scientists must search for knowledge concerning fundamental, recurring relationships that are relevant and important to farmers in general, or at least to a large class of farmers. Individual farmers, in contrast, need to know which farming practices, methods, or enterprises are most likely to work for them within the their particular whole-farm system (Gerber, 1992). Scientists and farmers must realize that their needs and expectations about research are different. A better understanding of these differences may be the first step toward collaborative research that can meet the needs of researchers and farmers. Researchers and farmers alike need good science.

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EDITORIAL cont'd from p. 2

What should authors do when faced with such results? The choice that most researchers would probably make (and the one chosen here) would be not to compare results across the two experiments. After all, agriculture is highly sensitive to many sources of variability, and we should not expect that two experiments necessarily would give identical results.

But this answer doesn't deal with the discrepancies; it simply defines them away by declaring the two experiments to be "independent," even though they were identical in all reported conditions. Most agricultural researchers probably would accept this reasoning. To do so is dangerous, however. Not to deal with the apparent discrepancies is to say, in essence, that an experimental result does not necessarily apply *anywhere* else (or that one is not on guard against the possibility of having made a serious mistake). Researchers are accustomed to acknowledging that a specific result might not apply on a different soil type, or under a different production practice. But are we prepared to acknowledge something much more worrisome, namely, that a conclusion reached at one location does not let us confidently say anything about *any* other place whatever?

My interpretation of the discrepancies in the present paper is not that agricultural phenomena are so variable that it is hopeless to try to learn anything from a field experiment. Rather, it is that we must try harder. The discrepancies must have an explanation. However, the explanation lies outside what was taken into account in the paper, because in all reported conditions the two experiments were *identical*. Therefore, either a mistake was made, or there was an important but overlooked difference between the experimental sites.

Clearly, there is a problem here. Yet both experiments — either of which might have been published alone, in which case there would have been no indication of any problem — followed standard procedures. Maybe this means that standard procedures are not always good enough. Perhaps they should routinely offer more protection against mistakes, through redundancies that provide us with consistency checks (as happened to be available in this paper, although not by intention). Second, to the extent feasible, the experimental design should encompass more sources of variation, both management-related and environmental, beyond those that are the primary focus of the experiment. This will tell us how sensitive the results are to changes in other conditions. Otherwise, we don't really know what is going on; something else than what the experiment was intended to learn about might be more important than the experimental variables. In the present paper, for example, something caused some results for the *same treatment* in different experiments to diverge by as much as *different treatments* in the same experiment. Similarly, in many field experiments, although the treatment variables have a statistically significant effect, they "explain" only a small fraction of the total observed variance. This should be a warning that we may be missing the point entirely. If we have that much plot-to-plot variation just from inhomogeneities *within* the experimental area, even though the entire experimental area was supposed to be uniform (except in the treatment variables), what does that tell us about how much the results might have changed on a different field?

Granted, to include variables that otherwise would have been ignored means we must devote more effort per experimental question, which reduces the number of questions we can investigate. However, doing fewer experiments, but doing them thoroughly and convincingly, may be preferable to doing more experiments where the ignored variations overwhelm the phenomenon being studied. We don't learn much from an experiment where the range of applicability is unknown, or, even worse, where it might not extend at all beyond the specific circumstances under which the data were collected.

No doubt some *AJAA* readers have thoughts on this question. We invite you to send them to us; if we get an adequate response, we will publish them as a forum. Perhaps we can stimulate more thinking about what we think is a critical but inadequately discussed issue in agricultural research.

Government Pledges to Reduce Pesticides, Promote Sustainable Ag

Only days before the release of the National Research Council's report on pesticide risks in children, the Clinton Administration pledged to reduce pesticide use and promote sustainable agriculture.

A joint statement by Agriculture Secretary Mike Espy, Environmental Protection Agency Administrator Carol Browner, and Food and Drug Administration Commissioner David Kessler, M.D., said, "We will intensify our effort to reduce the use of higher-risk pesticides and to promote integrated pest management, including biological and cultural control systems and other sustainable agriculture practices, under the leadership of the USDA. We will work side by side with American farmers to help test and implement improved and safer methods of pest management already used by many farmers."

Several days later, Browner said, "We'll work with American farmers to promote alternative farming methods that don't use any pesticides at all," and said EPA would monitor more closely pesticide residues on fruits and vegetables, and gather more information on children's eating habits.

Superpigs and Wondercorn. 1992. By Michael W. Fox. Lyons & Burford, 31 W. 21st St., New York, NY 10010. 209 pp. $21.95, hardcover.

Michael Fox, a veterinary ethologist with an international reputation for his work on dog and cat behavior, has devoted the past seventeen years to the cause of animal and environmental protection. During this time, he has produced about a book a year, ranging from popular and scientific treatises on dog and cat behavior, to children's stories involving animals, to scientific critiques of farm and laboratory animal management, to works aimed at the general public that criticize our present treatment of animals and nature. The current book falls into the last category. It employs his usual mix of quotations and gleanings from the scientific literature, public policy analyses, and ethics and theology to weave a picture of a technocratic society that he sees as virtually unregulated and unchecked in its search for profitable biotechnological fixes to find new markets or to solve problems caused by earlier technological innovations.

The new biotechnology (as opposed to old biotechnologies such as cheese-making and brewing) is the new 'high-tech' frontier for corporations and nations competing for multi-billion dollar markets. The technical roots of these new ventures lie in the exploitation of nucleic acid enzymes that have provided molecular biologists with revolutionary tools to play with DNA and RNA and to move genes around within cells and between organisms. In the past decade, this technology has been used in many ways: to discover many mutations that are responsible for human diseases; to manufacture therapeutic products such as insulin and blood clotting factors in cell bioreactors; and to develop new varieties of plant foods, with the possibility of producing plants and animals that are resistant to diseases or to biocides.

Dr. Fox does not condemn the technology outright, nor does he deny its tremendous potential for doing good. However, he focuses on the potential for doing harm that stems from current human attempts to master and dominate nature rather than trying to live in harmony with it. He provides several quotes from notable scientific authorities to bolster his argument that the prevailing scientific worldview is too centered on technical mastery, and that scientists can avoid paying adequate attention to environmental, social and ethical questions.

I agree that we have paid inadequate attention to these wider issues, and that society either has no mechanisms, or only inadequate mechanisms, to address and debate them thoroughly and productively. The Patents and Trademarks Office, for example, is definitely not set up to address social and ethical questions relating to patenting animals; it merely takes its lead from the courts. But the Supreme Court's 5-4 decision in favor of patenting Chakrabarty's *Pseudomonas* bacterium, which had an enhanced ability to degrade crude oil, barely addressed possible ethical questions. Dr. Fox also criticizes the regulatory structure for biotechnology products (more accurately, the lack of what he would consider effective regulation). He states that it is absurd that regulation of biotechnology products should be based on the type of product rather than on the process used to reach that product.

I tend to part company with him on this claim. I do not think that insulin produced by a bioreactor should be subjected to special requirements merely because it comes from a gene that is spliced into a bacterium. However, the production process may be relevant, as in the case of the tryptophan supplement that caused illness and death because of some byproducts produced in the bioreaction process. Where we probably agree is that it is inappropriate to regulate a bacterial pesticide in the same way as a chemical pesticide because of the fundamental differences in their behavior in nature. The chemical may break down and end up in groundwater, but the bacterium is a living organism that has a life of its own. This means that the impact of a living pesticide must also be examined on an another level. But it may still be appropriate to keep the regulation of a bacterial pesticide produced by biotechnology in the Pesticides program at the EPA.

Dr. Fox mentions briefly in several chapters that biotechnology can be a force for good. I would have liked to have seen him extend this idea to a complete chapter. We only gain hints of how complex it can be to balance the positive and negative impacts of some of the predicted biotechnology opportunities. I also would have liked to see more discussion of the views of the public, and their impact on the biotechnology debate. The survey results that I have seen all indicate that the public has concerns about biotechnology, but that in general they are more positive than negative. Thus, there is no broad groundswell of opposition to biotechnology, although particular products have run into problems, such as bovine somatotropin. What does the public really feel about this issue, and why has there not been more support for a sustainable philosophy? The fact that the American establishment still views growth as the basis of the American Dream surely is relevant to why there been only isolated opposition to biotechnology products and processes compared to Europe.

Questioning what he perceives to be the excessive attention to science and technology at the expense of ethics and environment, Dr. Fox has provided an interesting and provocative look at biotechnology.

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Last Oasis: Facing Water Scarcity. 1992. By Sandra Postel. W.W. Norton & Company, New York. 239 pp. $9.95, paper.

The hard truth is, the water we have is all the water we are going to get. There's not going to be any more.

As our numbers have grown and our economies have expanded and our technologies have proliferated, the amount of water available to quench our thirst, raise our crops and turn our turbines has not increased by so much as a cupful. We have reshaped the earth to capture water where

it is abundant so that it might flow where it is scarce. We have dammed and drilled and ditched and developed. We have drained swamps and reaped bounty from desert sands. We have built structures of great immensity and developed doctrines of great complexity, all to enable water to be moved and to be used to the benefit of man.

In *Last Oasis*, Sandra Postel, who has written extensively about water and other resource issues for Worldwatch Institute, where she is Vice President for Research, writes that we have developed one water source after another, as a caravan of pilgrims travels from oasis to oasis. Now, Postel argues, we have come to the last oasis. We can no longer count on the water to bubble from the sands or pour from the distant mountains. At the last oasis, water is not solely a product of the richness of the earth. It is a product of human ingenuity and care.

In addition to being an intriguing metaphor, *Last Oasis* is a rich and concise analysis of prevailing practices and approaches in water development. In the opening chapters of *Last Oasis*, Postel focuses on the limits of immensity and complexity in water development. The "cheap" water has been claimed. The costs of traditional water development have spiraled upwards, while the benefits of those massive projects have become more elusive. Moreover, the environmental and social costs have been greater than we realized.

Last Oasis also is an illustration of how water conservation in effect could create new water supplies where current supplies are dwindling. Postel explains that water scarcity is not limited to arid lands where shortages are attributable to inadequate rainfall. Scarcity also is becoming more common in temperate, well-watered regions where demands for water are increasing and water supply projects are becoming more difficult and more costly to build, or where withdrawals from groundwater sources are exceeding the sustainable yield.

As the limits of the prevailing approaches to water development are reached, our limited existing water supply should be made to do more, Postel argues. *Last Oasis* provides a wide ranging review of information on the science and engineering of water conservation. Postel discusses the application of conservation techniques to a broad spectrum of water uses, and notes that agriculture, as the largest user of water, is where increased efficiency in water use might have the greatest benefit. For 5,000 years, most farmers have irrigated their fields in the same way — by flooding or channeling water across their cropland — losing an average of 60 percent of the water in the process. New and more efficient technological systems are being developed and applied, however, such as drip irrigation, "surge" irrigation, and low energy, precision application sprinklers that promise to do more with less water. In addition, older, more traditional "low-tech" methods of water retention — such as walls, terraces, grass, catchments, and cover crops — are being reexamined, and often are found to be effective in increasing the efficiency of irrigation systems.

Postel argues, however, that conservation is not solely a matter of finding an engineering solution to an engineering problem; indeed, the engineering mind-set that has guided water development for thousands of years comes under direct and repeated attack. Beyond engineering, Postel emphasizes the roles played by management, economics and law in governing water use and misuse. She also discusses economic barriers to rational water policies, such as pricing water to reflect the unsubsidized cost of capturing and storing it at the source of supply and transporting it to the place of use. Postel also gives attention to legal constraints on water conservation, such as restrictions on selling or transferring water rights to where the water could be used more efficiently.

After a largely successful effort to underscore the importance of conservation in assuring the availability of water, the last chapter of *Last Oasis* turns to the central question behind this book: If conservation makes economical, social and environmental sense, why isn't everybody doing it?

At the heart of the matter for Postel is "modern society's disconnection from water's life giving qualities." We see water only as a resource. We are quick to assume rights to water, but slow to recognize an obligation to preserve and protect it. The answer Postel proposes is a water ethic, the inspiration for which was Aldo Leopold's "land ethic." Its essence, she says, "is to make the protection of water ecosystems a central goal in all that we do." Postel foresees a wide range of benefits from adopting a water ethic, from environmental well-being and economic equity to sustainable development, political decentralization, and international justice.

The problem, however, remains the same. If a water ethic makes economical, social and environmental sense, as Postel argues, why doesn't everybody share it? The problem is that water conservation is not the only game in town, and the protection of water ecosystems is only one of many "ethics" that guide, or are likely to guide, the actions of individuals and institutions. Some of these ethical positions — better health care, better education, assured food supplies — are consistent with the adoption of a water ethic. Other ethical positions that are held just as strongly, such as national security and economic expansion, can be inimical to a water ethic.

The development of more insightful, more sensitive ethical positions toward water undoubtedly is desirable. The urgent need for water conservation described in *Last Oasis*, however, cannot wait for the evolution of a water ethic. Ethical systems are complex and ingrained; change may take generations, and cannot always be directed or predicted. Rather than ethical change, what will lead to more rational and more sustainable water policies are the direct actions that Postel describes: the global efforts to develop the technologies, research the techniques, educate the citizens, reform the markets, and revise the laws to remove the barriers to conservation. It is the experience and successes of these measures that will lead to the maturing of a broader, wiser vision of our ethical connection to "water's life giving qualities."

Last Oasis presents a valuable picture of the incremental successes that have been accomplished, and that can be accomplished, in the struggle for a more rational approach to water use and conservation. It

also presents an important vision of the difference that conservation can mean, and the changes in our societies and ourselves that a water ethic can incubate. Other books contain similar information, however, and other writers, including Leopold, have argued for an environmental ethic. Perhaps the lasting importance of *Last Oasis* will be its single, clear metaphor, an image that, like the silent spring and the spaceship earth, can communicate through its poetry when argument fails.

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BOOK NOTICES

World Soil Erosion and Conservation. 1993. David Pimentel (ed.). Cambridge University Press, 40 W. 20th St., New York, NY 10011. xii+349 pp. $99.95, hardcover.

This compendium presents 13 articles about soil erosion problems around the world, including both temperate and tropical countries. About half the authors are from Cornell University, the remainder from a wide range of countries. About two-thirds of the chapters cover individual countries, often in considerable detail. The rest deal with more general issues of conservation, sustainability and productivity.

Interacting Processes in Soil Science. 1992. R.J. Wagenet, P. Baveye, and B.A. Stewart (eds.). Lewis Publishers, 2000 Corporate Blvd. N.W., Boca Raton, FL 33431. 296 pp. $69.95, hardcover.

This book's seven chapters deal with the physics, microbiology, and chemistry of soils, soil management, and plant-soils interactions. The emphasis is on the linkages among these domains, which traditionally have been studied by separate subdisciplines. Basis soil processes examined include water movement, solute tansport, microbial activity, and soil-root interactions.

Crop Ecology: Productivity and Management in Agricultural Systems. 1992. R.S. Loomis and D.J. Connor. Cambridge University Press, 40 W. 20th St., New York, NY 10011. xiv+538 pp. $100, hardcover; $39.95 paper.

The first half of this book deals with general ecological principles applicable to the analysis of agricultural systems, and with the fundamental physical, chemical, and biochemical processes of crop production, including photosynthesis, nitrogen fixation, water relations, and respiration. These concepts are then applied to discussions of several significant agricultural resource issues, such as soil management, water management, and energy. The authors are respectively from the U.S. and Australia, and the book includes discussions of a major farming system of each country. The book is designed as a text for a graduate or advanced undergraduate.

Agricultural Ecosystem Effects on Trace Gases and Global Climate Change. 1993. L.A. Harper, A.R. Mosier, J.M. Duxbury, and D.E. Rolston (eds.). ASA Special Publication No. 55. American Society of Agronomy, 677 S. Segoe Road, Madison, WI 53711. xvii+206 pp. $30, paper.

This book consists of 14 chapters on various ways in which agriculture affects atmospheric levels of methane, carbon dioxide, and oxides of nitrogen, all of which interact with solar radiation and therefore can alter global climate. Major topics include: the fundamental agricultural processes that produce these gases, such as denitrification; the rate at which these gases are produced in various agricultural production systems; and measurement techniques. Emphasis is on the sources of trace gases, rather than on their effects on climate or on policy implications. The treatments generally are on a highly technical level, suitable for professionals in fields such as soil chemistry and soil microbiology.

Pesticide Reforms Needed to Protect Children, Says Report

Pesticide policy reforms are needed to reduce or eliminate risks posed by pesticides in food, in particular those foods of special importance in the infant and child diet, according to a report recently released by the Environmental Working Group. Infants and children are routinely exposed to combinations of two or three pesticides per food, according to the report, which differs from the National Research Council report *Pesticides in the Diets of Infants and Children* in its method of determining risk.

"When cancer risks from just 8 pesticides in 20 fruits and vegetables are added, the average child exceeds the EPA lifetime one-in-one-million risk standard by his or her first birthday," the report says. It also says millions of children in the United States receive up to 35 percent of their entire lifetime dose of some carcinogenic pesticides by age 5. It recommends a "targeted pesticide risk reduction strategy that will gradually but completely phase out pesticides that present the greatest hazards to children."

Pesticides in Children's Food is available for $15 plus $3 handling from EWG, 1718 Connecticut Ave., NW, #600, Washington, DC 20009; (202)667-6982.

Guide for authors

The American Journal of Alternative Agriculture (AJAA) publishes original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multi-disciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. See Vol. 5, No. 1, pp 2 & 3, for an explanation of the various categories of articles.

Units

Research papers should use the International (SI, or metric) system throughout. Occasional use of common unit equivalents in parentheses is permitted, mainly for relatively exotic SI units.

Title page

The title page should give the following information (all flush left): 1) title of the paper; 2) names of authors; 3) affiliation and office address of authors, and 4) acknowledgements, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Key words

Provide subject matter key words suitable for use in scientific indexing.

Reference list

When citing material that has been covered in more than one format, such as the typescript of a conference presentation and a journal article, preference should be given to the version that is most readily available, and that is likely to remain so. Generally this means standard publication channels, such as books, journals, and regular government report series. Unpublished or informally-published material should be cited only when no alternative form exists.

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Use initials only for first and middle names. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized. Page numbers are written out in full (e.g., 1108-1123, not 1108-23). The volume is given if page numbers begin at 1 for each issue.

Citing references

Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

Manuscript preparation

The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Follow the section headings style used in this AJAA issue. All headings are flush left, with no underlining or italics.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Leave extra space to separate columns. Every figure and table should be mentioned at least once in the text.

Submission of manuscripts

Submit four high-quality copies to Editor, American Journal of Alternative Agriculture, Suite 117, 9200 Edmonston Road, Greenbelt, MD 20770. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form; that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of the family farm.

Low-input alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Henry A. Wallace Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization formed to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

The Institute also provides these services:

- *A resource to lawmakers and others who influence agricultural research, education, and information policy*
- *A voice for alternative agriculture in Washington*
- *A sponsor of research and education outreach programs*
- *A national clearinghouse for information on alternative agriculture*
- *A publisher of reliable scientific information on agricultural sustainability*

If you're interested in helping us, please contact the Henry A. Wallace Institute for Alternative Agriculture, 9200 Edmonston Road, Greenbelt, MD 20770. The phone number is (301) 441-8777.

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